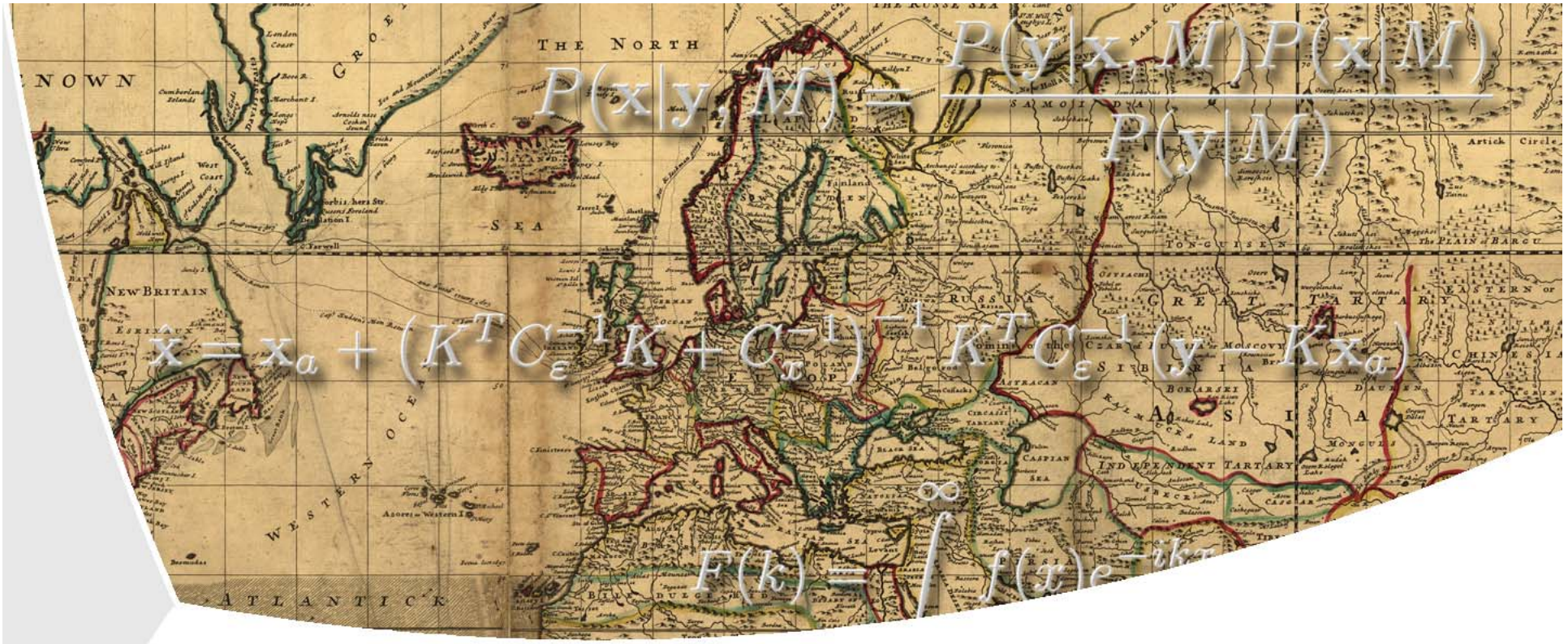


TerraSAR-X SAR Data Processing

H. Breit, T. Fritz, U. Balss, A. Niedermeier, M. Lachaise, B. Schättler

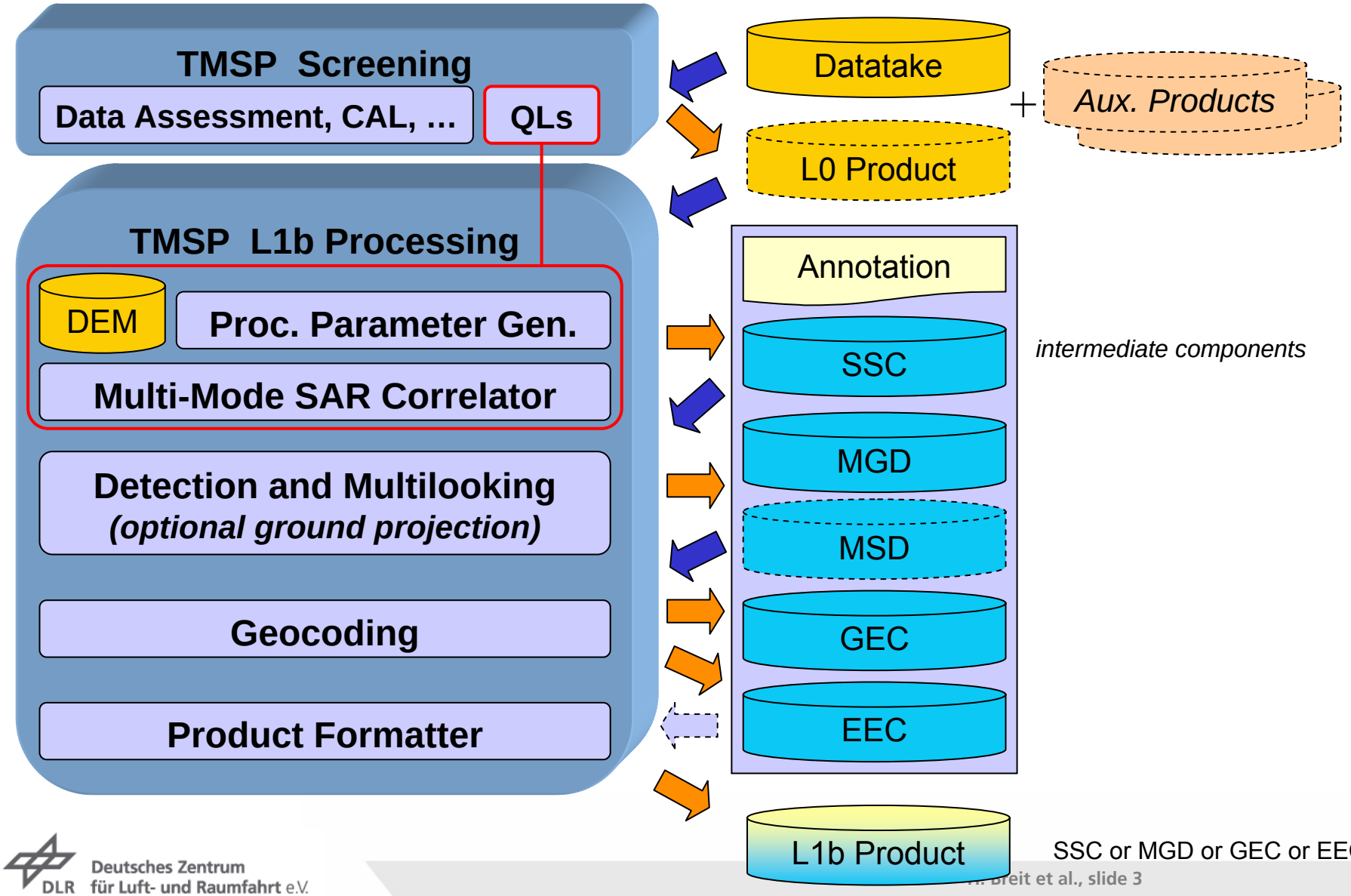
CEOS SAR Calibration and Validation Workshop 2008

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

Content

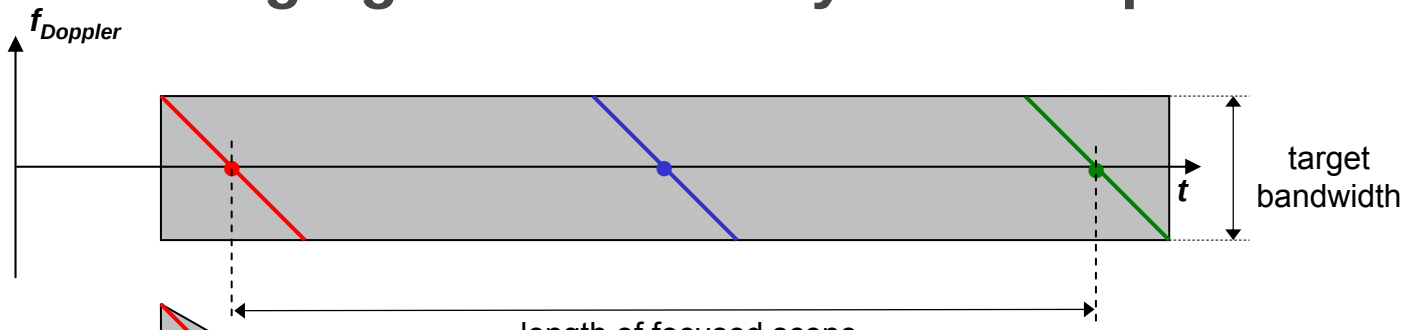
- TerraSAR Multi-Mode SAR Processor (TMSP) Functional Overview
- Calibration Pulse Processing and Replica Generation
- Spectral Weighting
- Product Location Accuracy and Radiometric Accuracy
- Noise Correction

TMSP Functional Overview

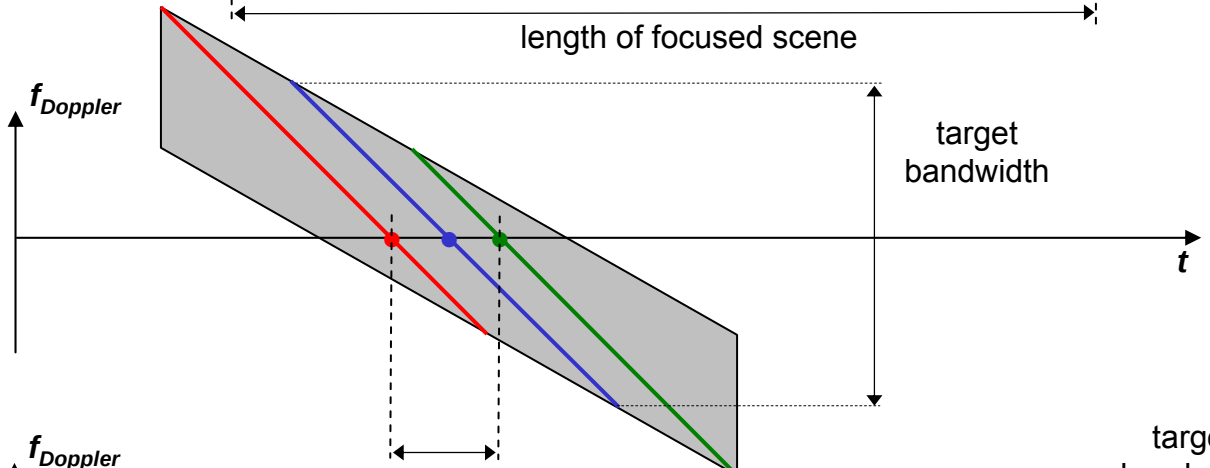


TerraSAR-X Imaging Modes and Synthetic Apertures

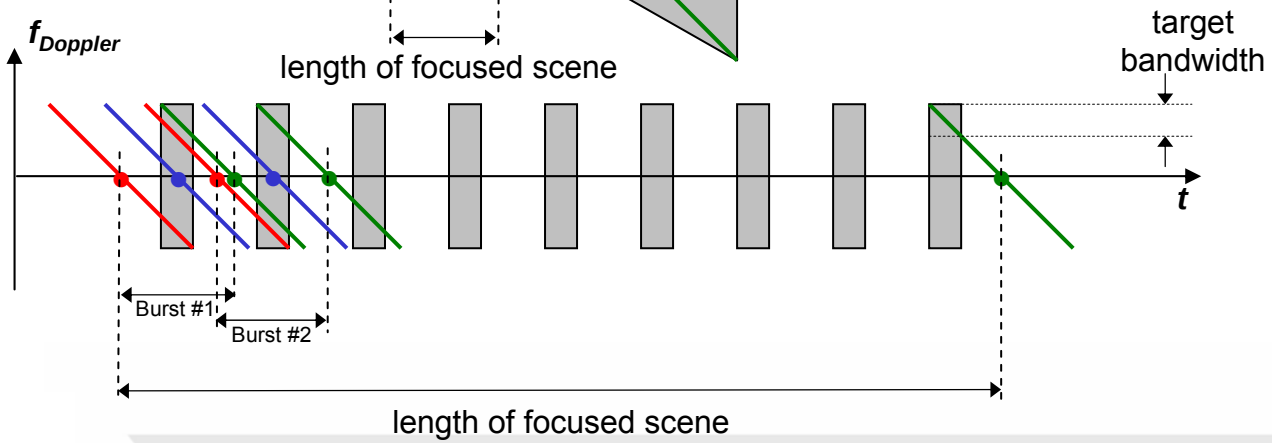
Stripmap



Sliding Spotlight



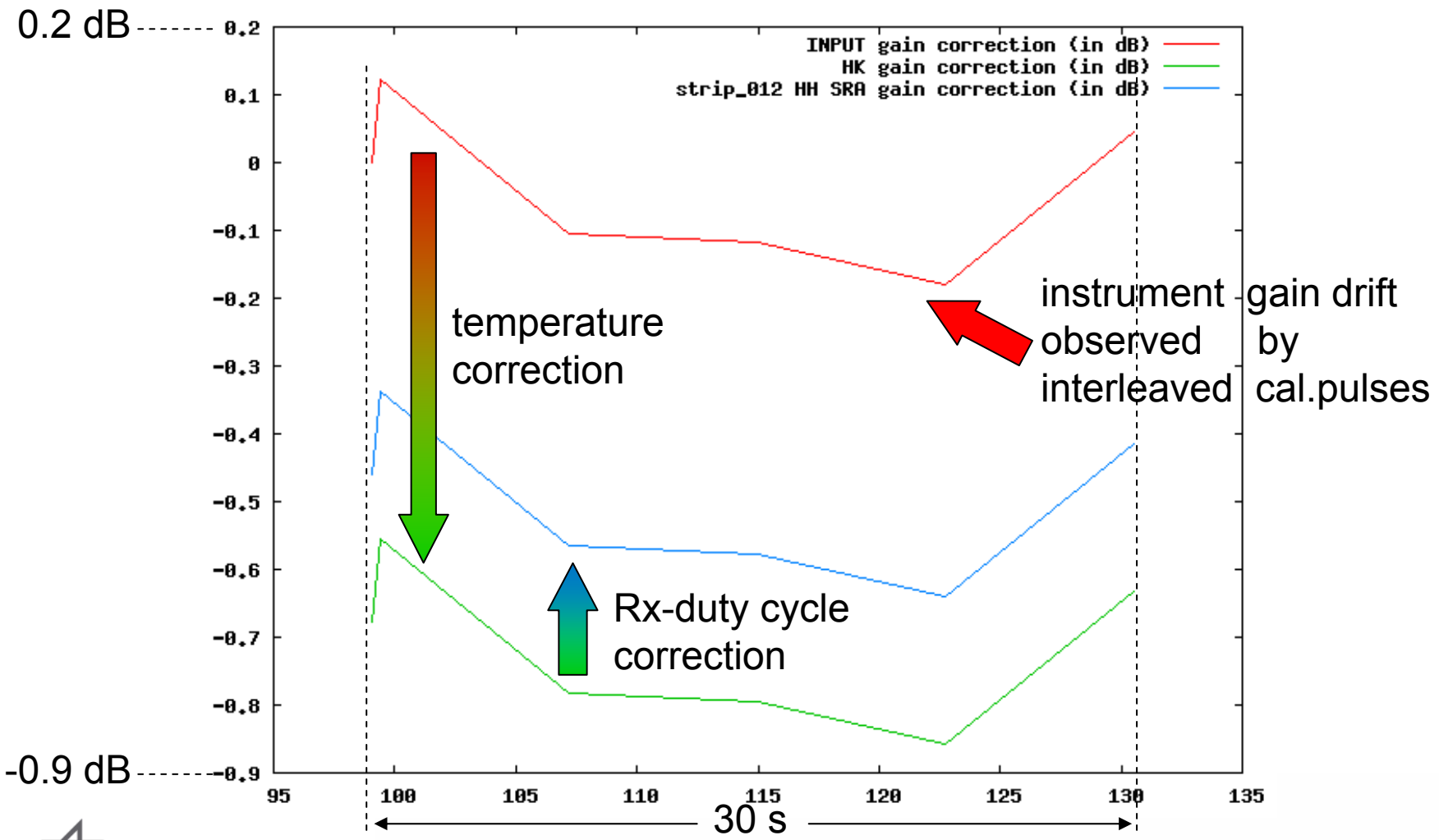
ScanSAR



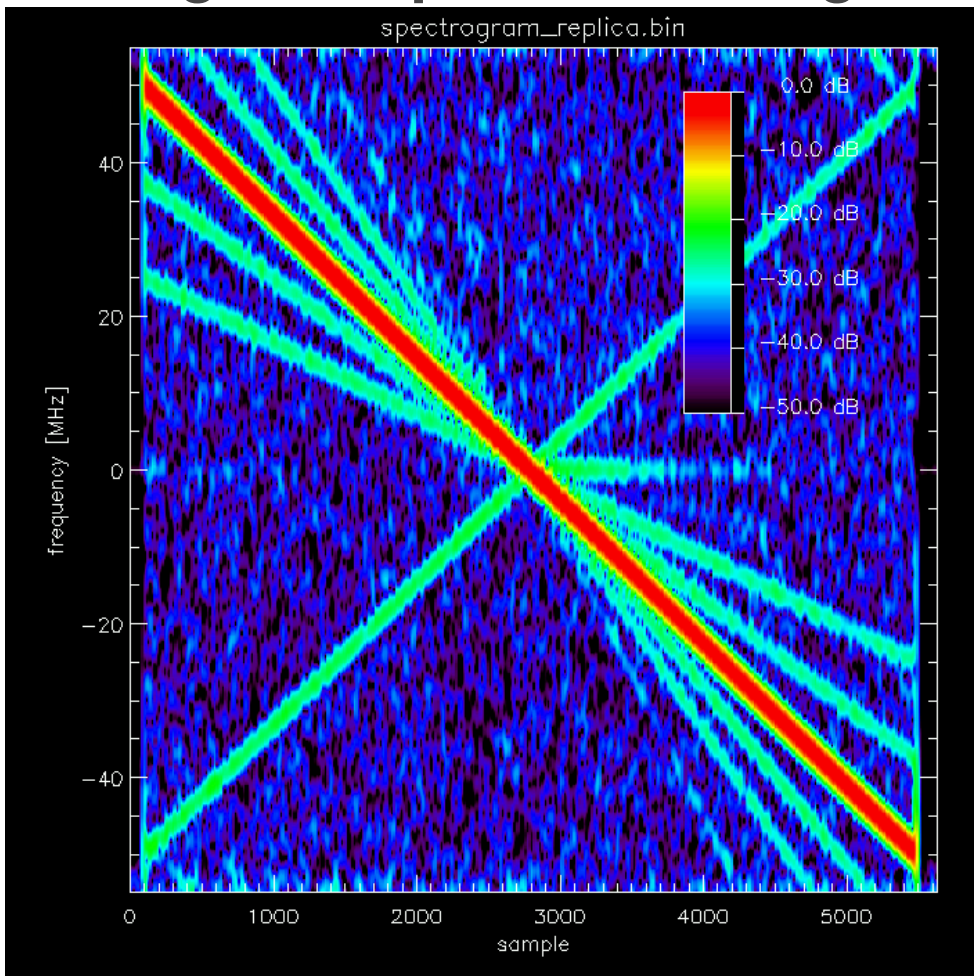
Radiometric Calibration

- Internal calibration (calibration pulses track gain and phase drifts of the instrument during a data take).
- Calpulse evaluation
- Correction of calibration pulses for temperature and Rx-duty cycle dependency in the TMSP.
- Replica generation
- Processor normalization
- Projection of the elevation antenna pattern based on attitude data using DEM data
- Azimuth antenna pattern correction based on Doppler centroid (geometry and signal) estimates.
- External calibration (corner reflectors, transponders, antenna pattern models) provides antenna patterns and calibration constant.

Instrument gain drift covered by interleaved cal. pulses



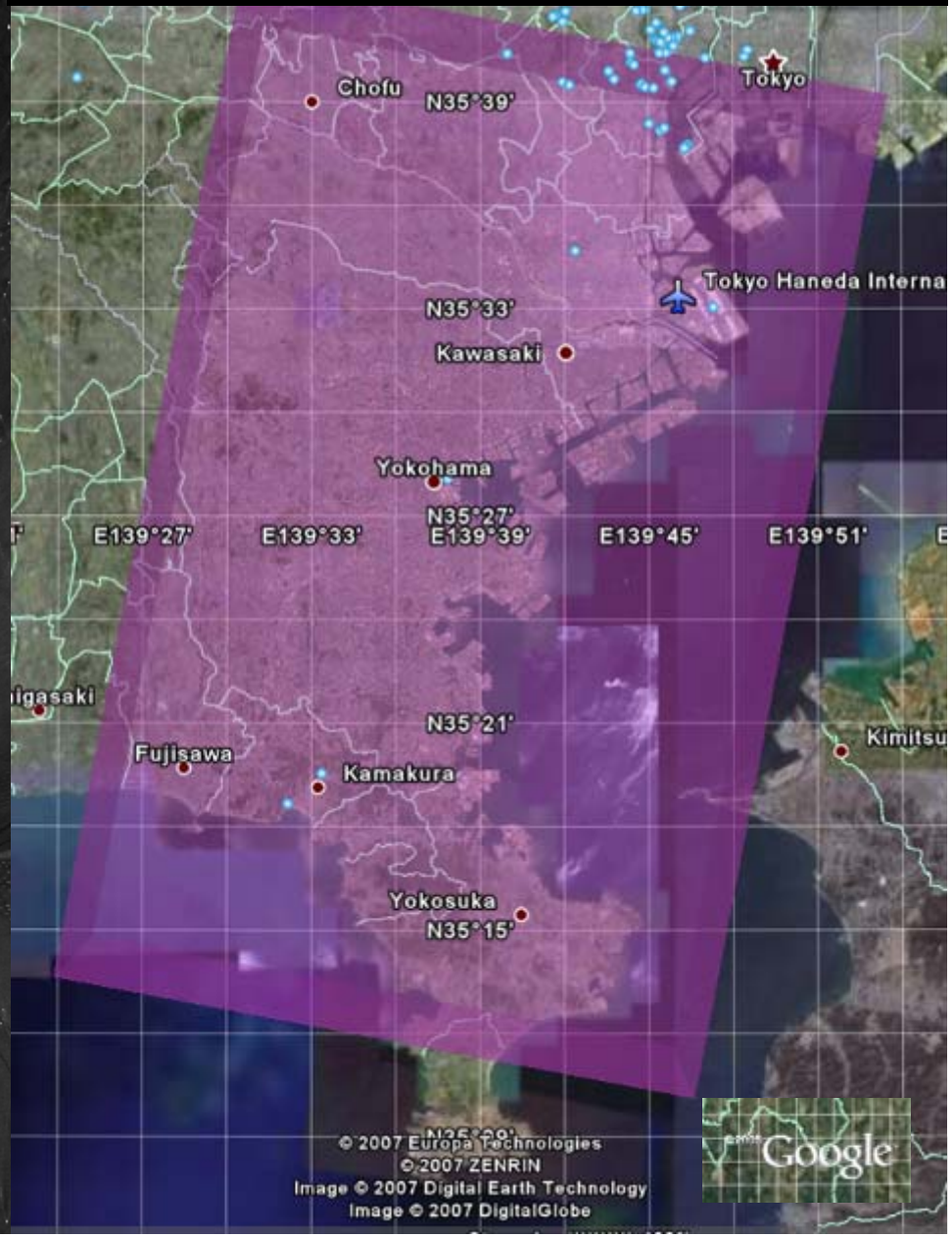
Digital Replica Focusing

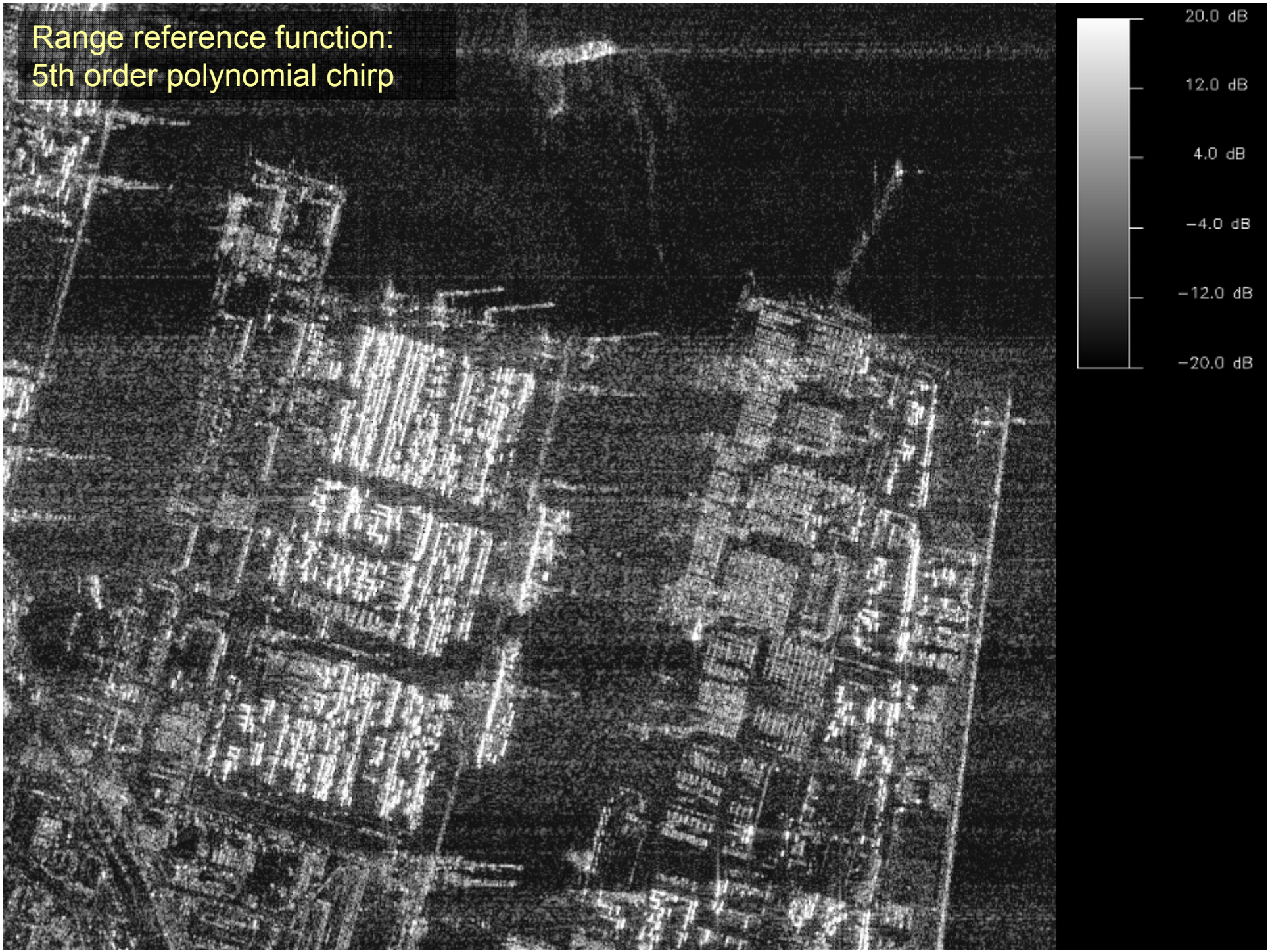


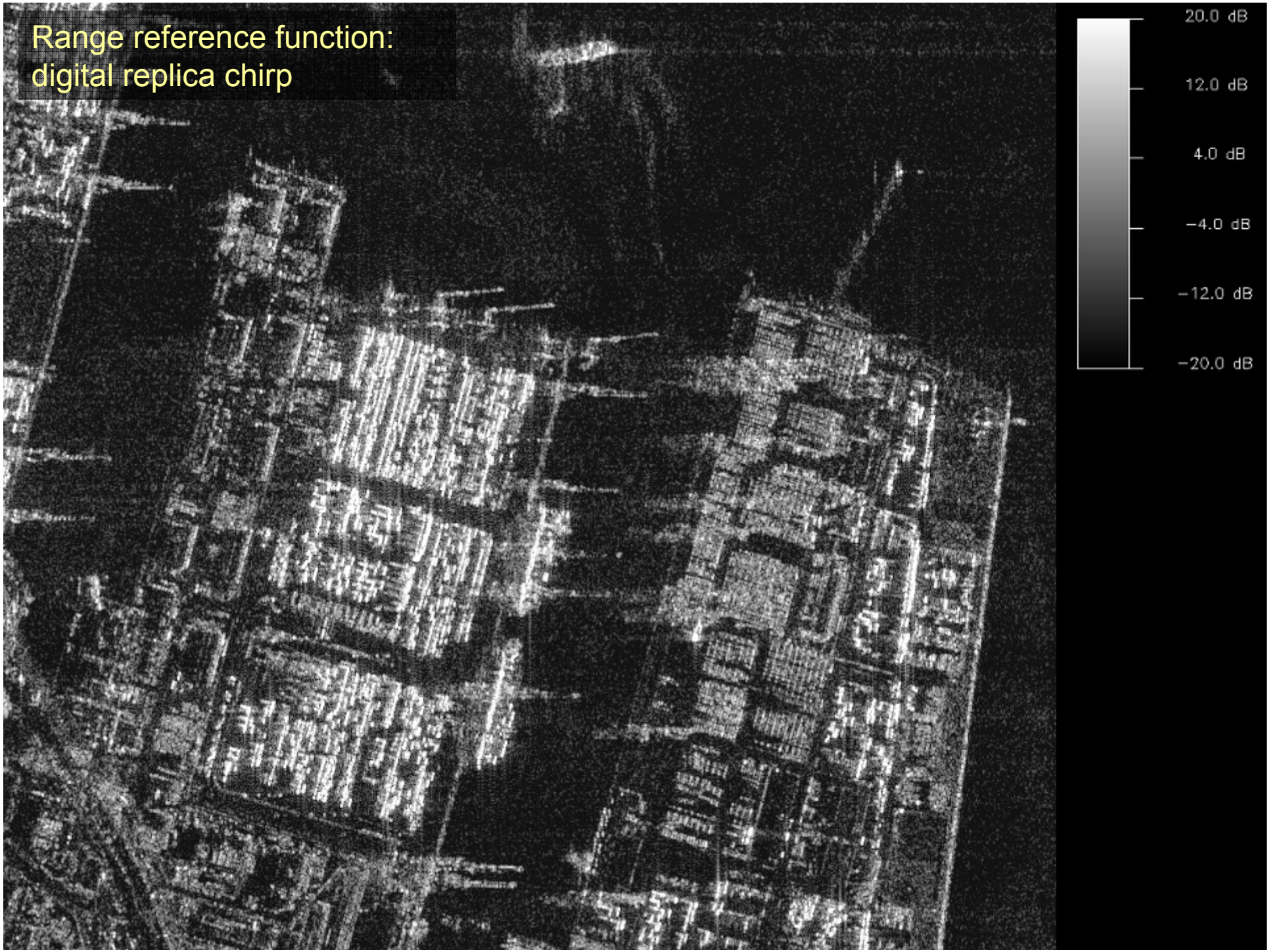
Spectrogram of a digital 100 MHz down-chirp replica reconstructed
from the instrument's internal calibration loop measurements.

Besides the nominal chirp additional chirp frequency rates are present

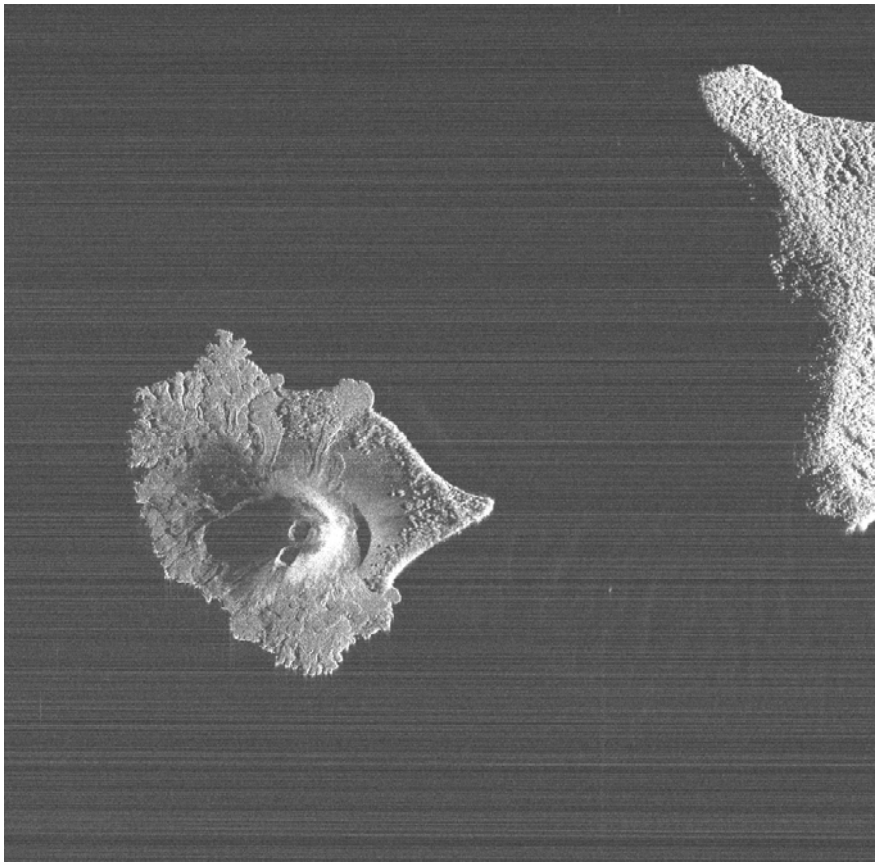
Stripmap SSC, 20071021, θ ≈ 26°,
Yokohama, Japan




Range reference function:
5th order polynomial chirp
20.0 dB
12.0 dB
4.0 dB
−4.0 dB
−12.0 dB
−20.0 dB


Range reference function:
digital replica chirp
20.0 dB
12.0 dB
4.0 dB
−4.0 dB
−12.0 dB
−20.0 dB

A short and rare (< 1‰) visit in the “trap” of <u>blind</u> deconvolution

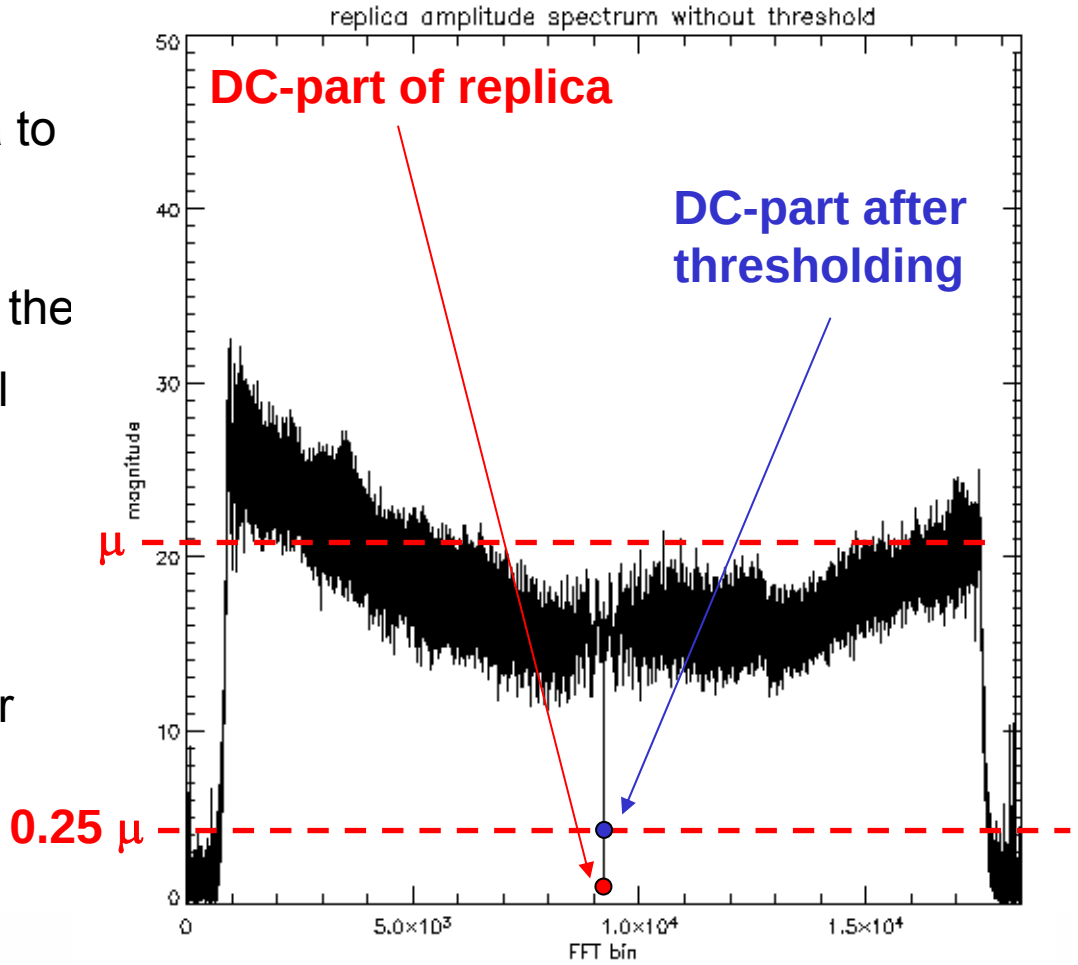


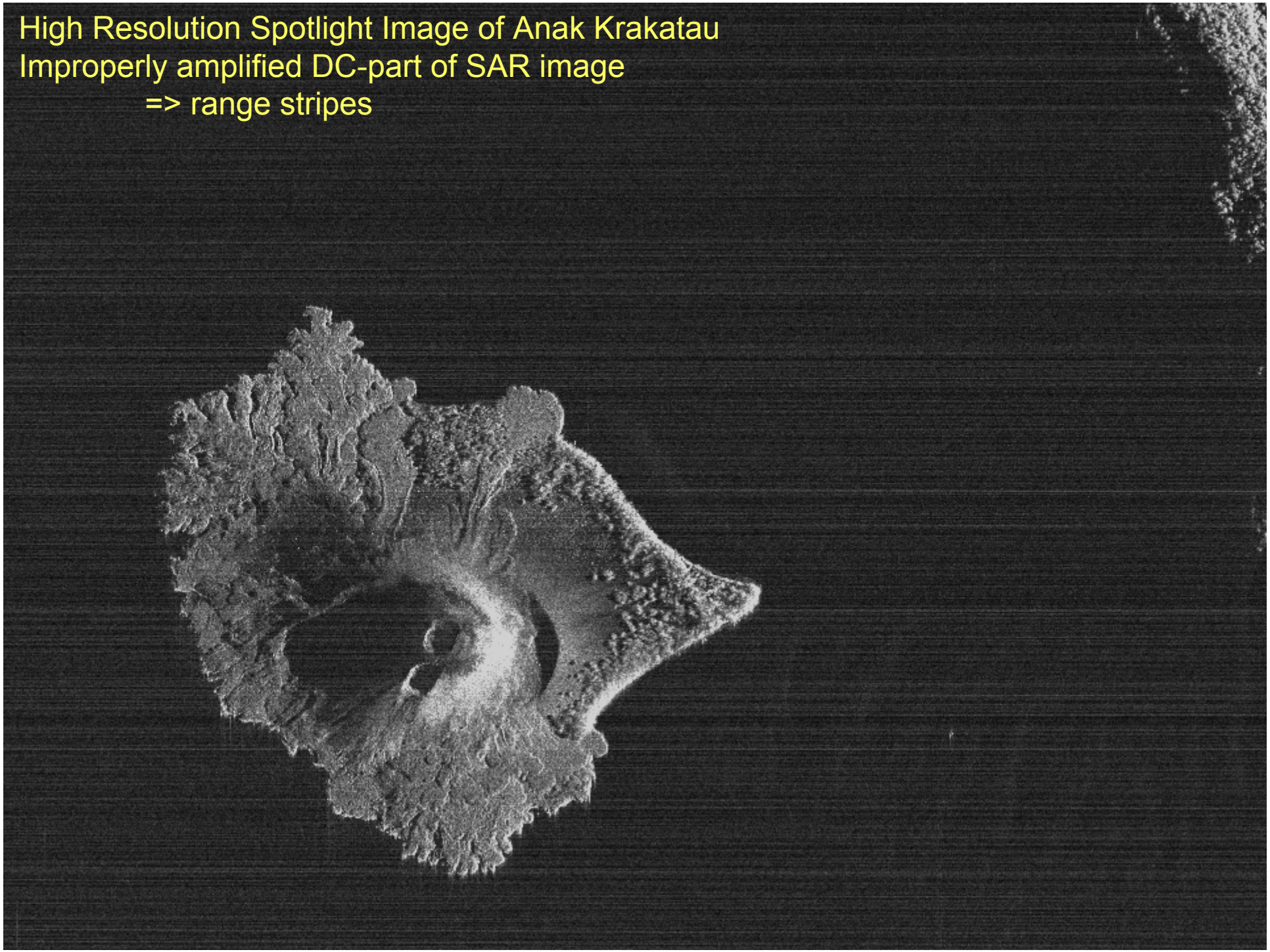
Range Compression with Spectral Thresholding

- ADC offset corrections applied during replica generation may cause the DC-part of the replica to be close to zero.
- In case of a DC-part in the SAR signal not as close to zero as in the replica (due to noise and/or differing ADC offsets) this signal component is improperly high amplified during range deconvolution:

$$RC(f) = U(f) / Replica(f)$$

- Spectral thresholding of the filter avoids over-amplification of the frequency bins close to zero
- Part of the TMSP since V4.2, April'08

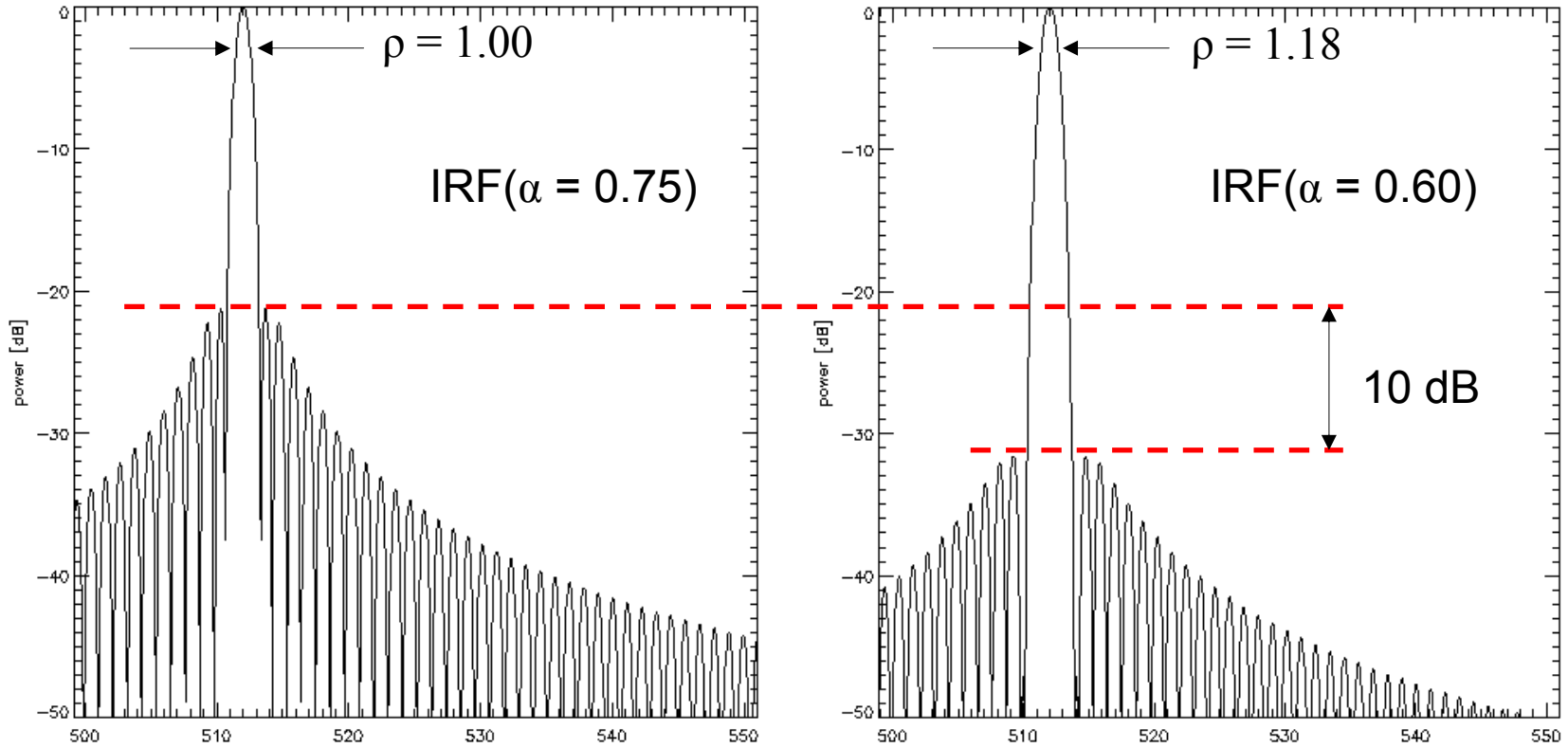



High Resolution Spotlight Image of Anak Krakatau
Improperly amplified DC-part of SAR image
=> range stripes


High Resolution Spotlight Image of Anak Krakatau
Spectral thresholding eliminates range stripes

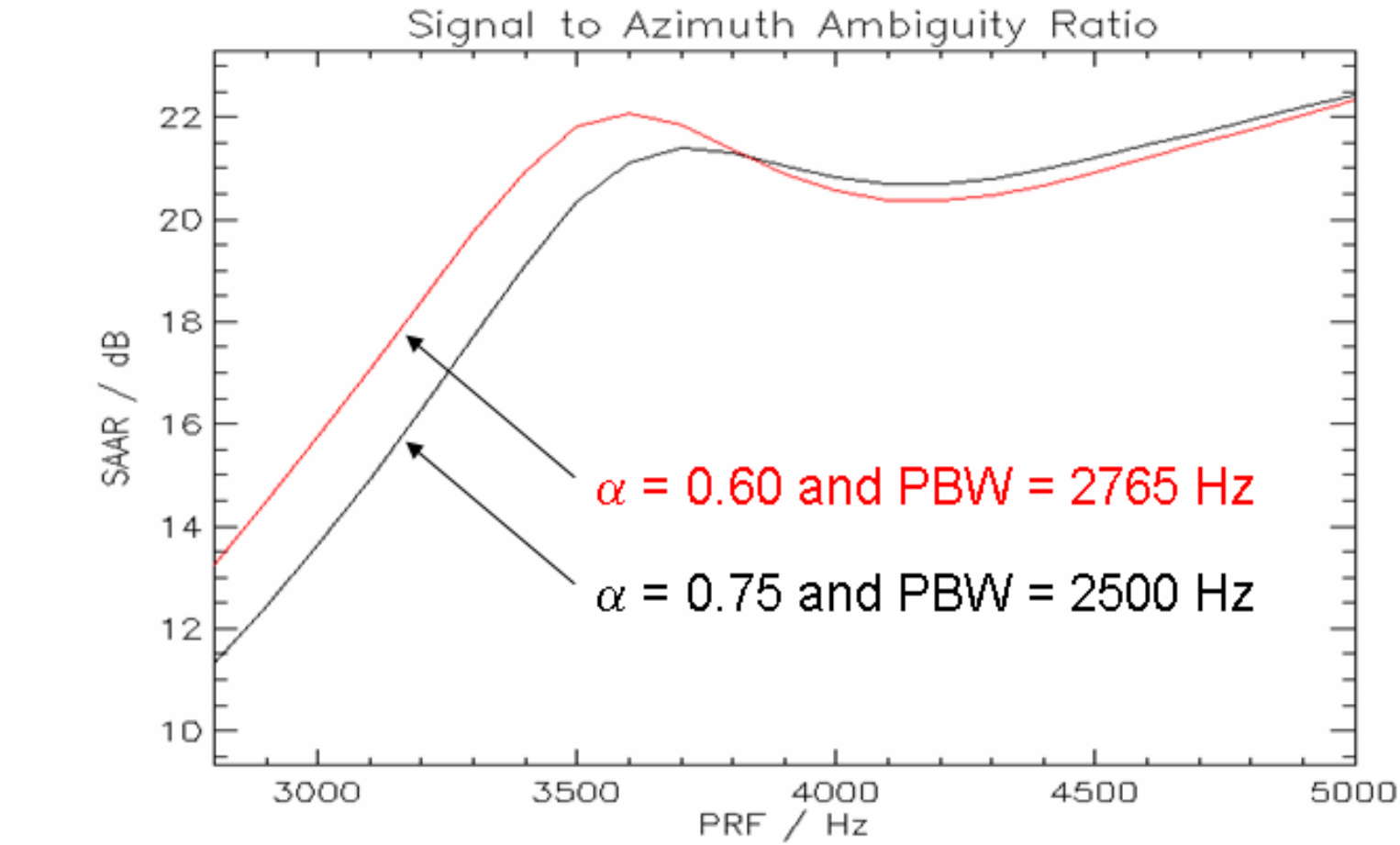
Range & Azimuth Spectral Weighting

- from a theoretical point of view -

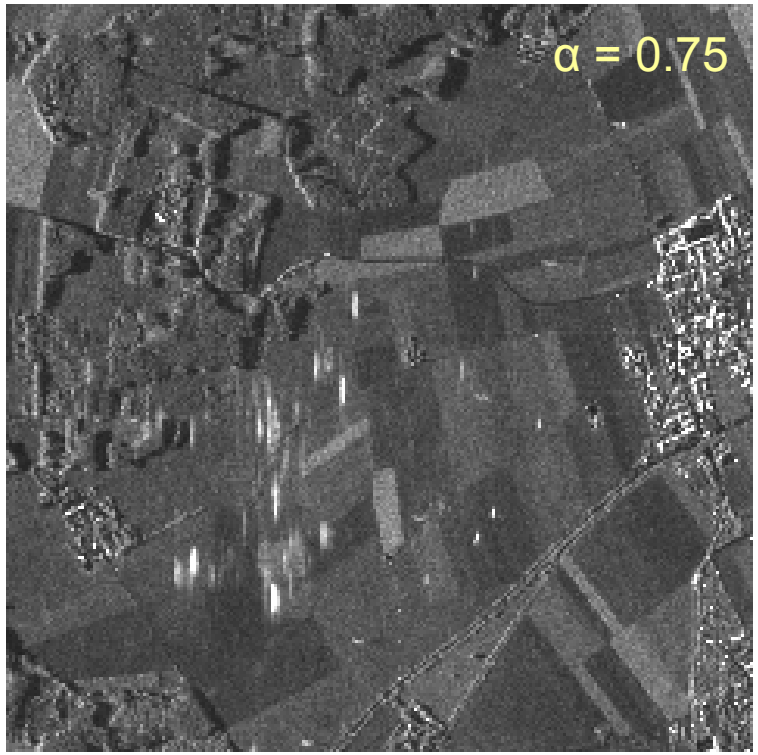


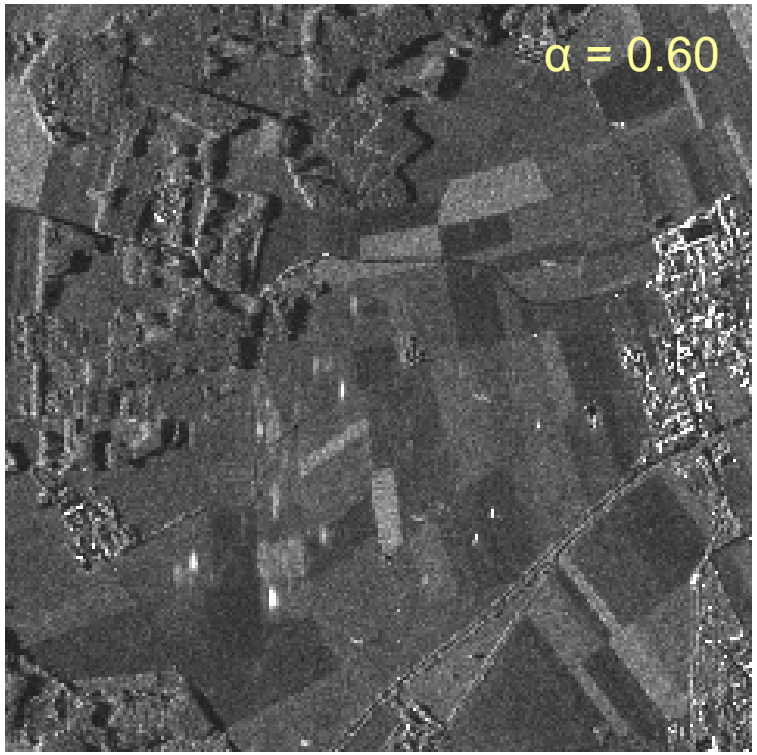
α	0.75	0.6
ρ	1.00	1.18
PSLR	-21.4 dB	-31.6 dB
ISLR	-16 dB	-19.5 dB

Spectral weighting improves Signal to Azimuth Ambiguity Ratio



Spectral weighting improves Signal to Azimuth Ambiguity Ratio



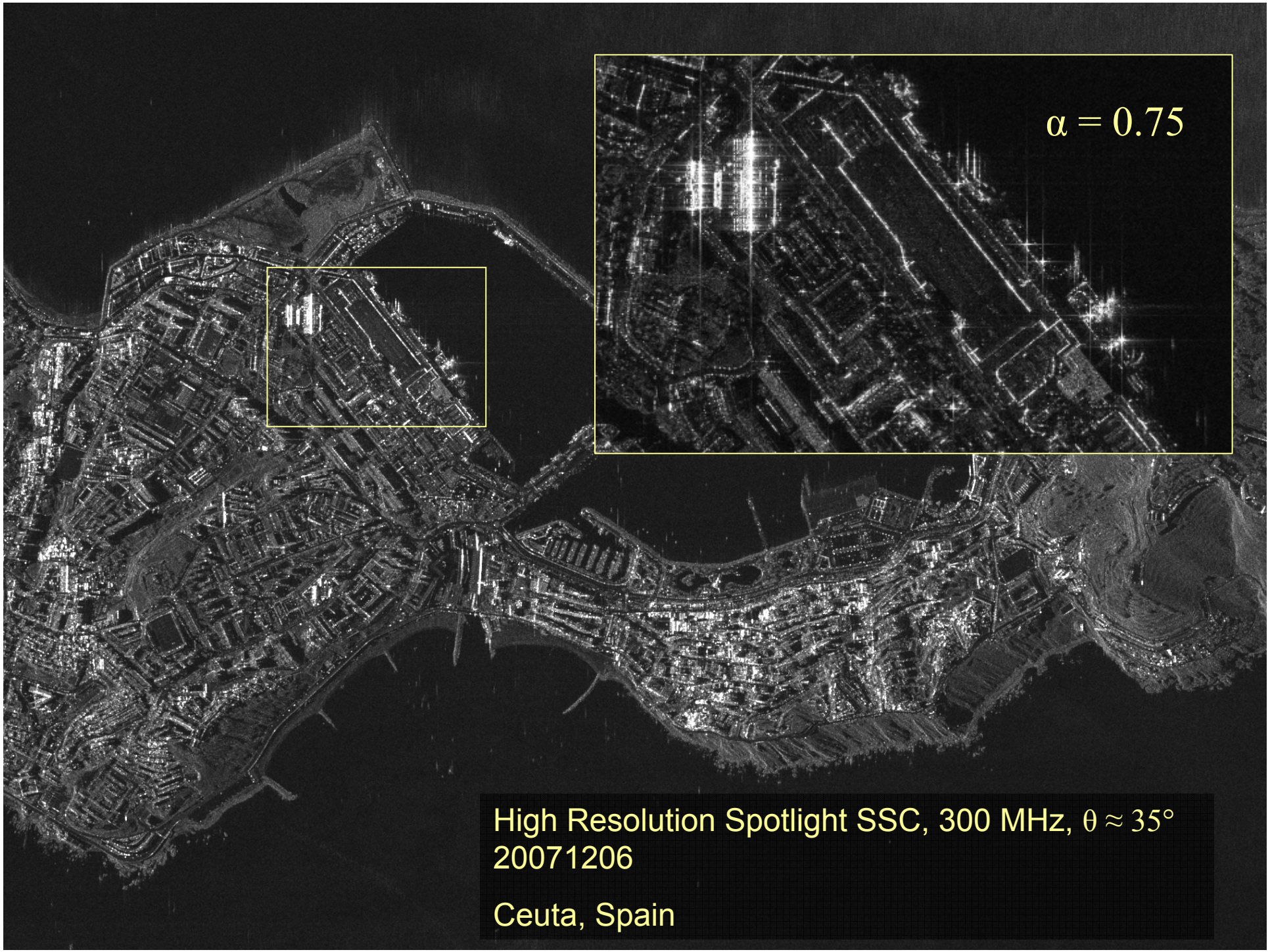


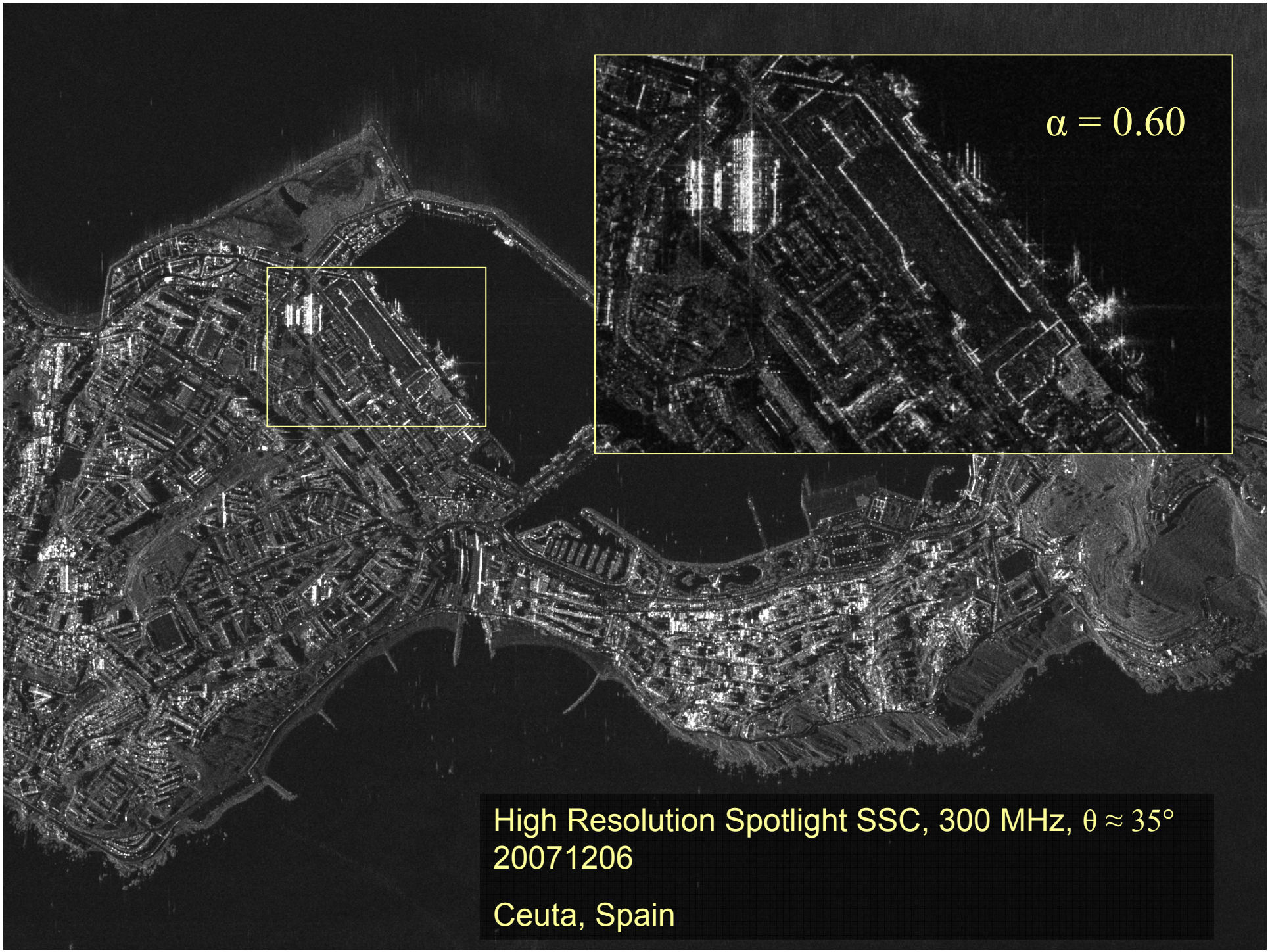
visible azimuth ambiguities in a Spotlight image acquired out of the full-performance range


MGD-SE, 3m resolution,
α = 0.75,
BW azimuth: 2500 Hz

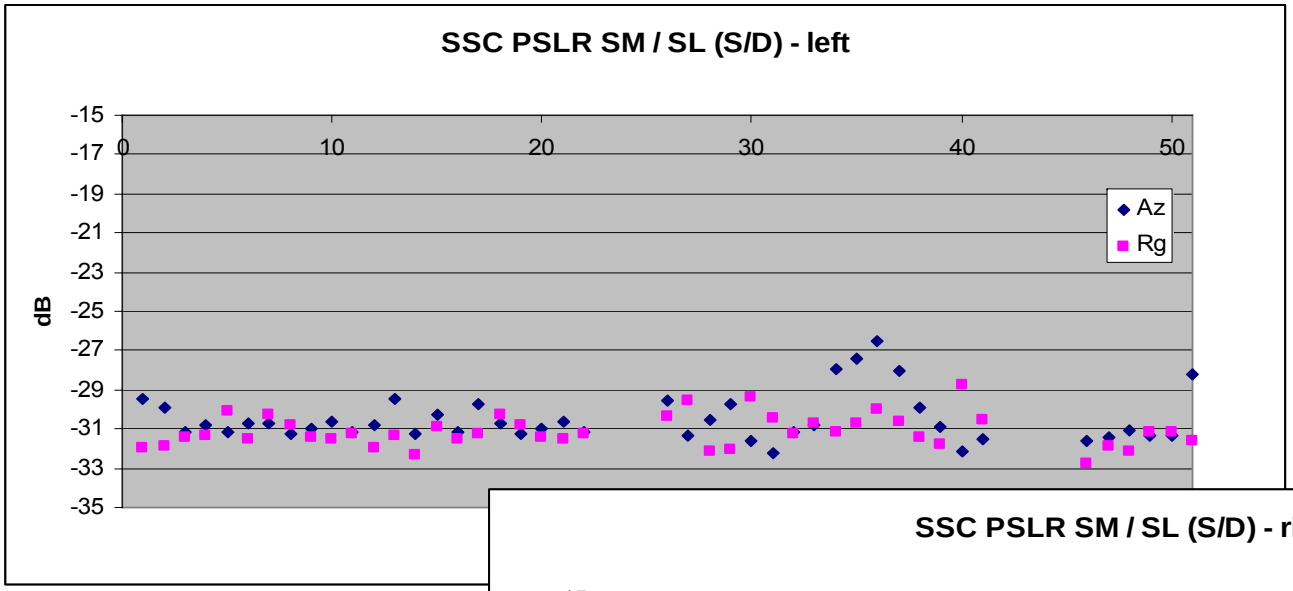

MGD-SE, 3m resolution,
α = 0.60,
BW azimuth: 2765 Hz

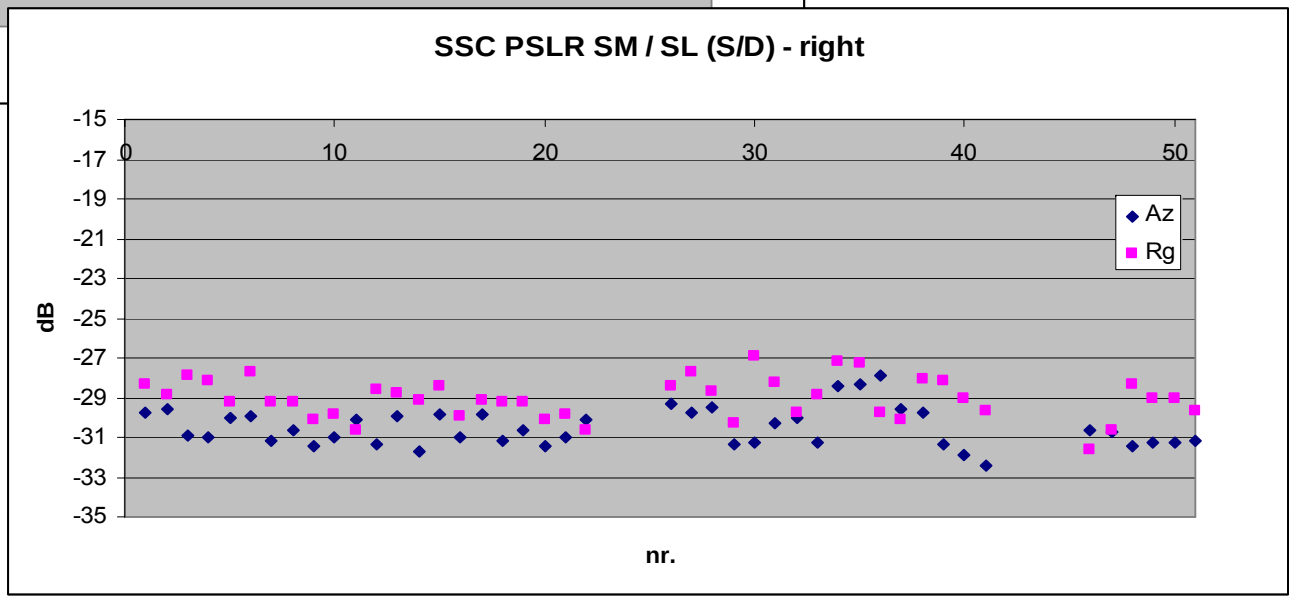

High Resolution Spotlight SSC, 300 MHz, θ ≈ 35°
20071206
Ceuta, Spain


α = 0.75
High Resolution Spotlight SSC, 300 MHz, θ ≈ 35°
20071206
Ceuta, Spain

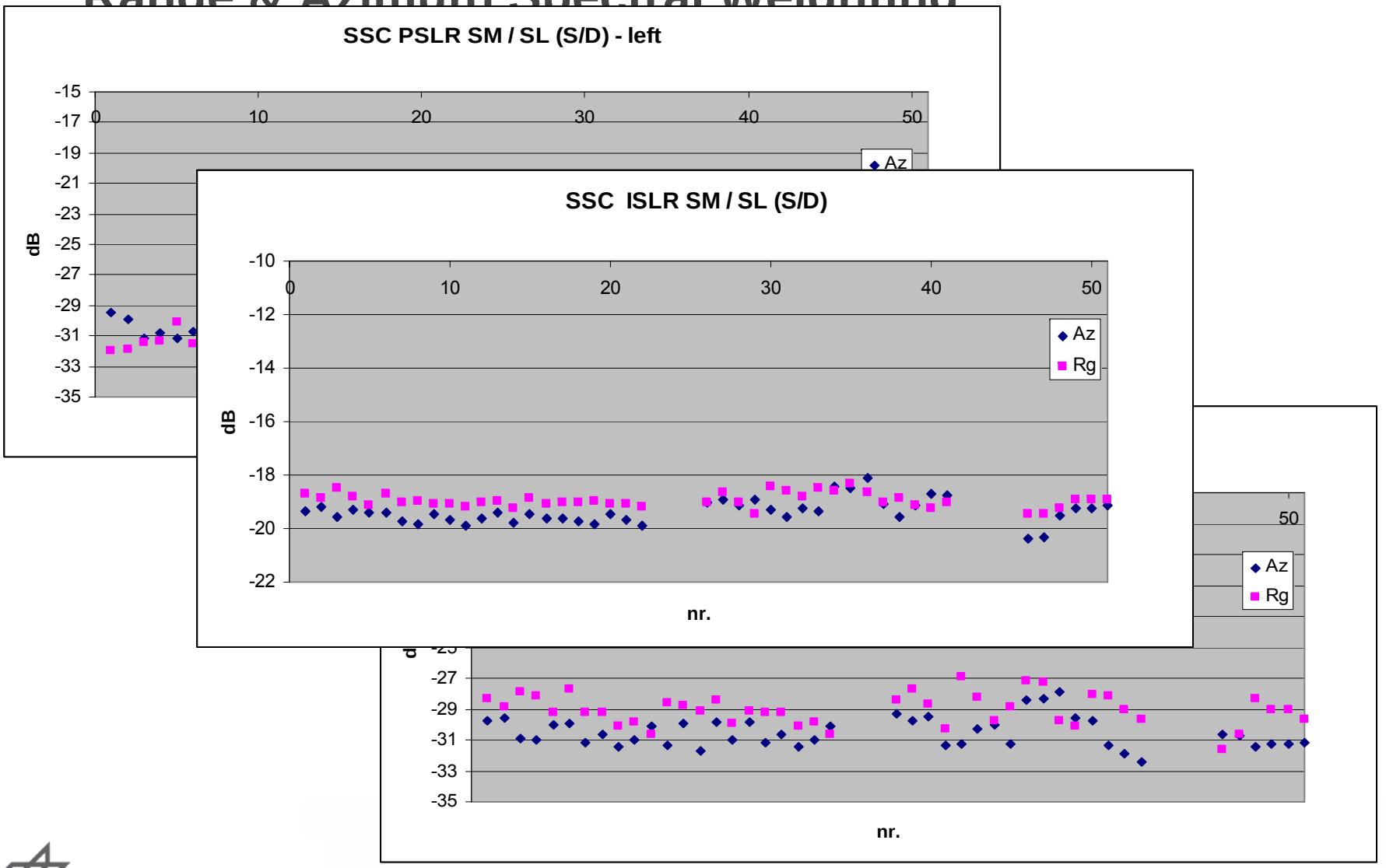

α = 0.60
High Resolution Spotlight SSC, 300 MHz, θ ≈ 35°
20071206
Ceuta, Spain

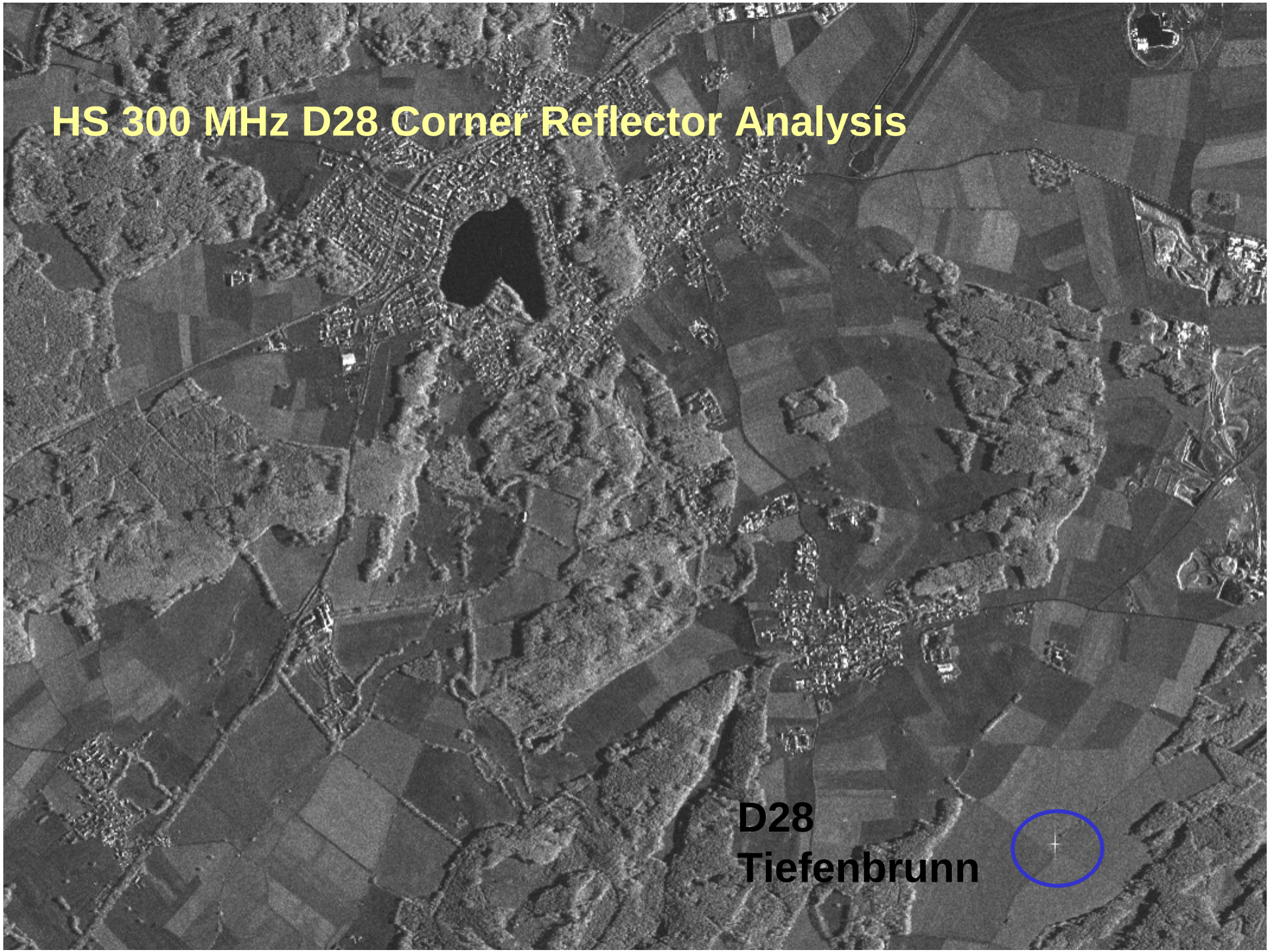
Range & Azimuth Spectral Weighting

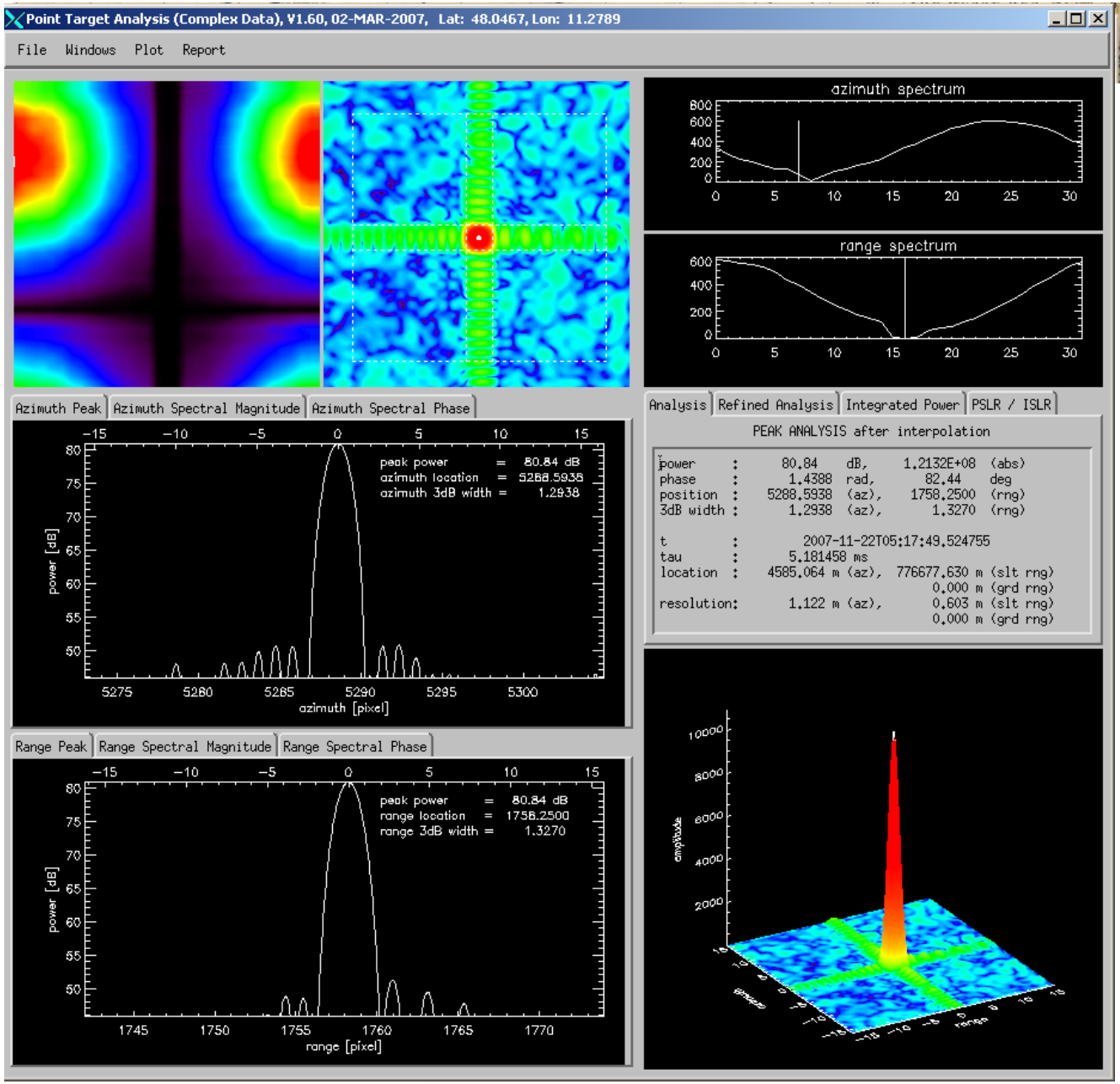




Range & Azimuth Spectral Weighting




HS 300 MHz D28 Corner Reflector Analysis
D28
Tiefenbrunn



Corner Reflector Analysis in HS 300 MHz Single Pol *SSC* (HH)

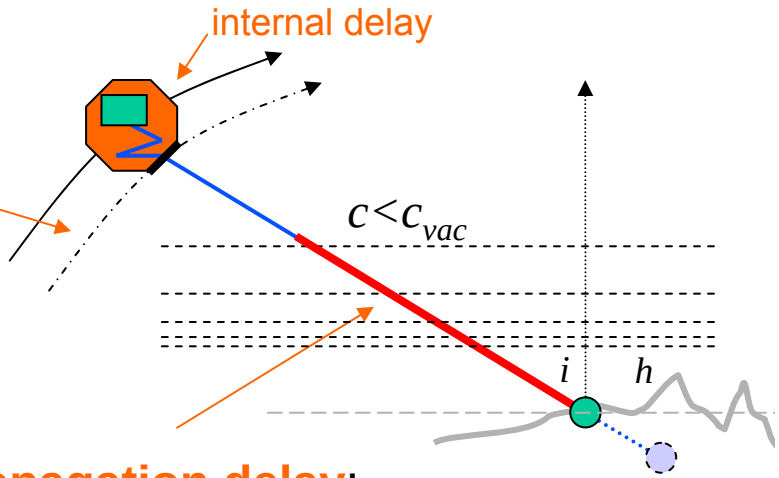
measured resolution

1.1 m (az)
0.6 m (sl rg)

specified resolution

1.1 m (az)
0.6 m (sl rg)

Geometric Corrections



Orbit state vectors (COG) are shifted to the geometric SAR antenna center using the current instrument **attitude** information during processing (approx. 80cm in range). *These are the annotated state vectors*.

TS-X products contain annotation of **signal propagation delay**:

- operational tropospheric delay correction by processor TMSP:

$$\Delta R^{Z}_{tropo}(h) = \frac{ZPD}{\cos(i)} \cdot e^{\left(\frac{-h}{H}\right)}$$

$$ZPD = 2.3m; H = 6000m$$

$$h = avr.DEM\ height\ of\ scene$$

$$i = mid\ scene\ incidence\ angle$$

	h = 0 m	h = 2500 m
near range (18 deg.)	**2.4 m**	**1.6 m**
far range (41 deg.)	**3.1 m**	**2.0 m**

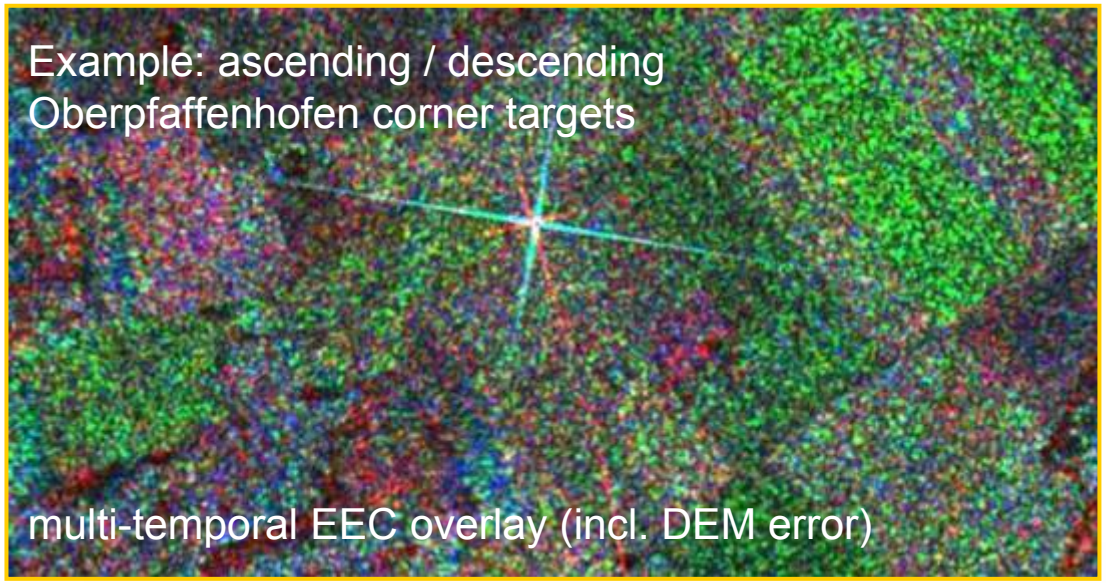
- ionospheric delay not significant for X-band:

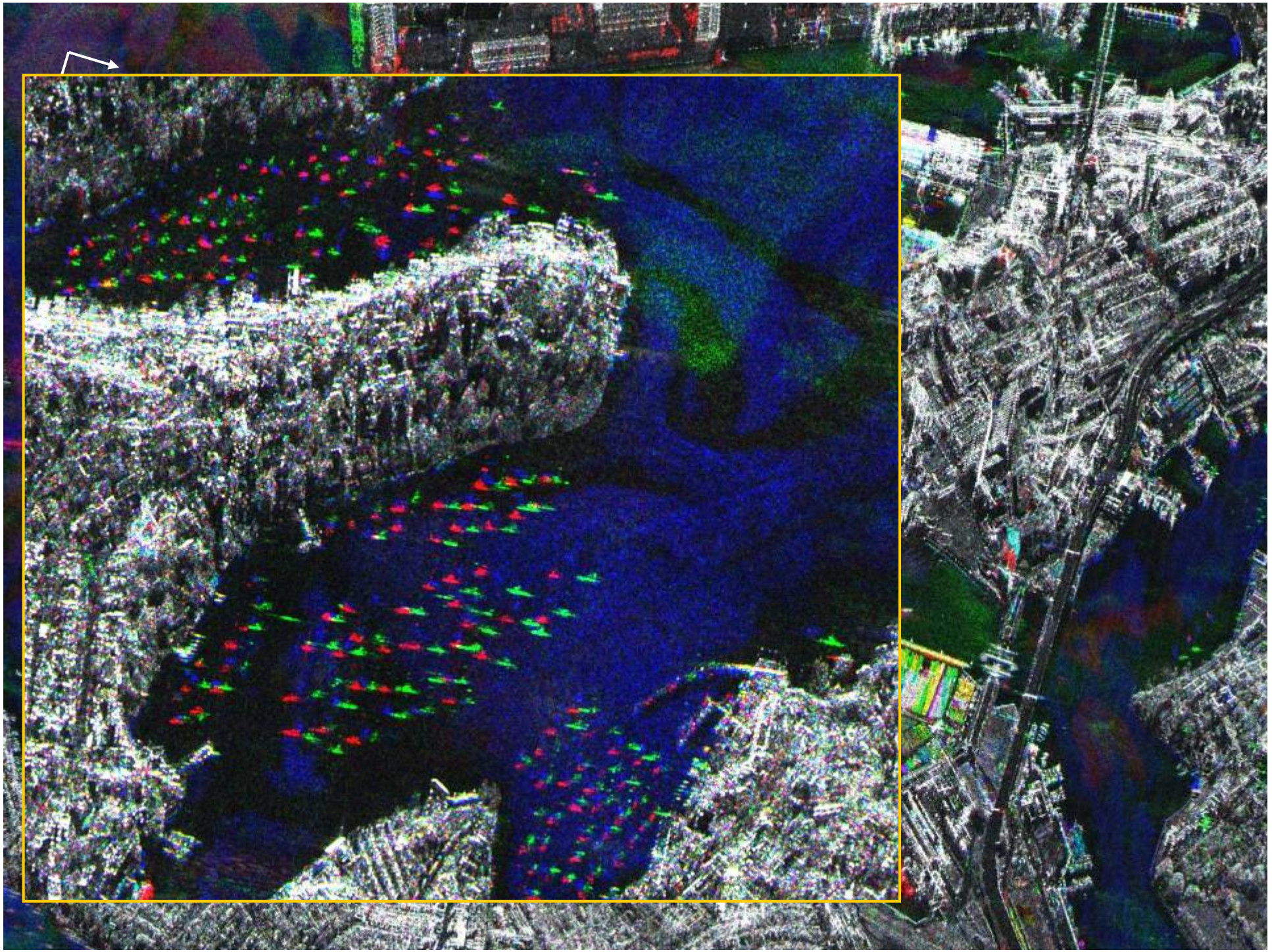
$$\Delta R^{\theta}_{iono} \approx \frac{K \cdot TEC}{f^2 \cdot \cos i}$$

TEC [TECU]	Delta R Z [m]
3	0.01
5	0.02
10	0.04
30	0.13
80	0.35

Pixel Localization Accuracy

- **achieved orbit accuracy** is well within spec. (science orbit error **<<** 20cm). Currently (low solar activity) close to **3cm**. “Rapid” orbit accuracy is very close to “science”.
- **tropospheric delay correction** refined and adjusted in collaboration with *calibration team.* L1b products are localized in sub-pixel range.
- **Measured absolute pixel localization accuracy** OP-CRs (rg/az): **30 cm / 53 cm (1sig)**
  independently verified by PASCO Tokyo CR measurements in CP (39 cm / 58cm)
- **specified absolute location error** **< 1 m**
  (sigma, *SSCs, science orbit*) including orbit errors (along track), propagation with different heights…



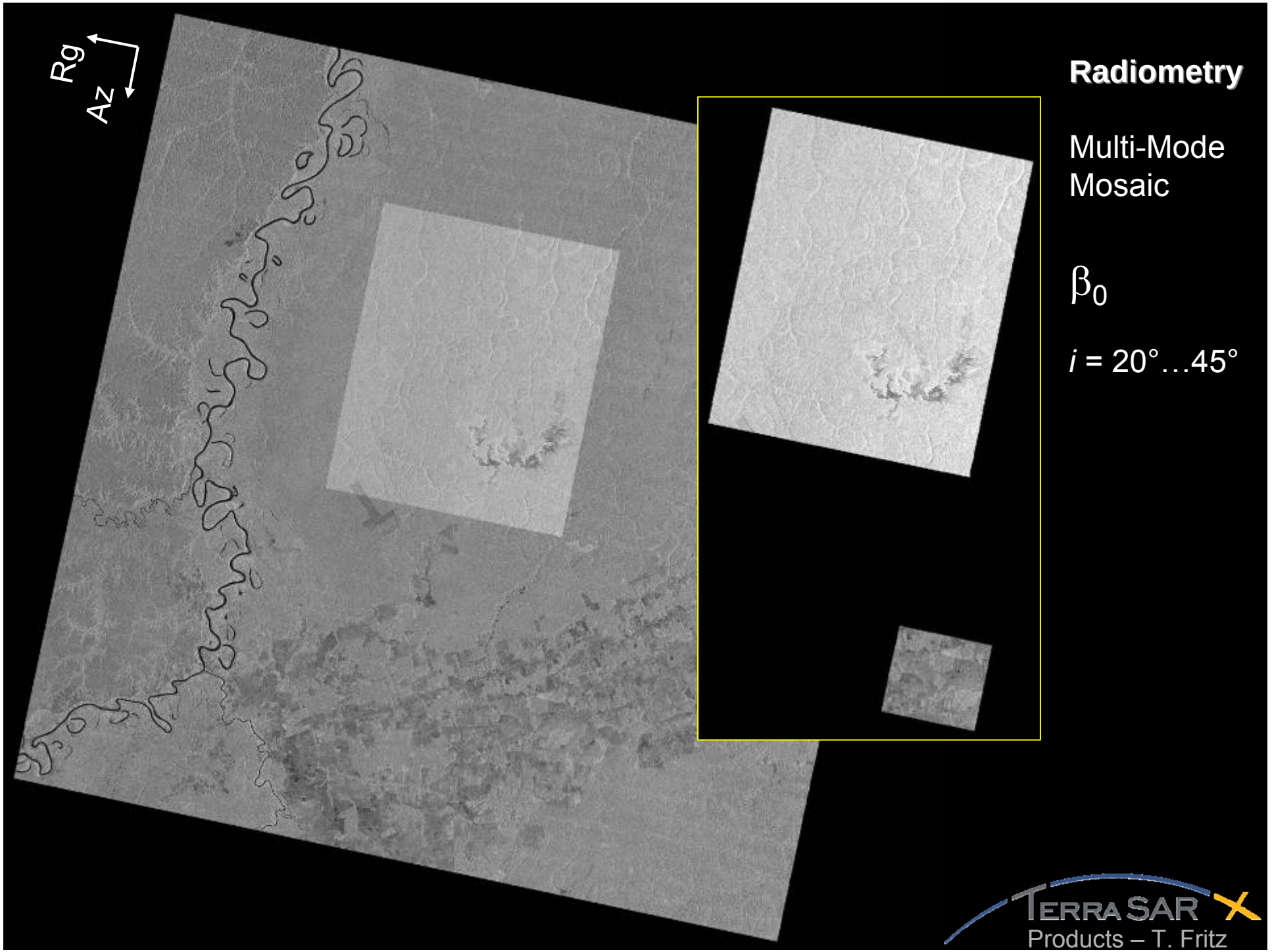


Product Verification / Validation with respect to Radiometry

Rainforest image analysis to verify and validate

- correctness of elevation antenna patterns
- correctness of elevation antenna pattern projection (geolocation and projection using a 10'' DEM)
- Compensation of chirp energy variations and instrument gain drifts
- processor normalization for all imaging-modes

Mosaics of standard L1b EEC products originating from different imaging modes and incidence angles have been transformed from β_0 to γ_0 using the annotated incidence angle mask.

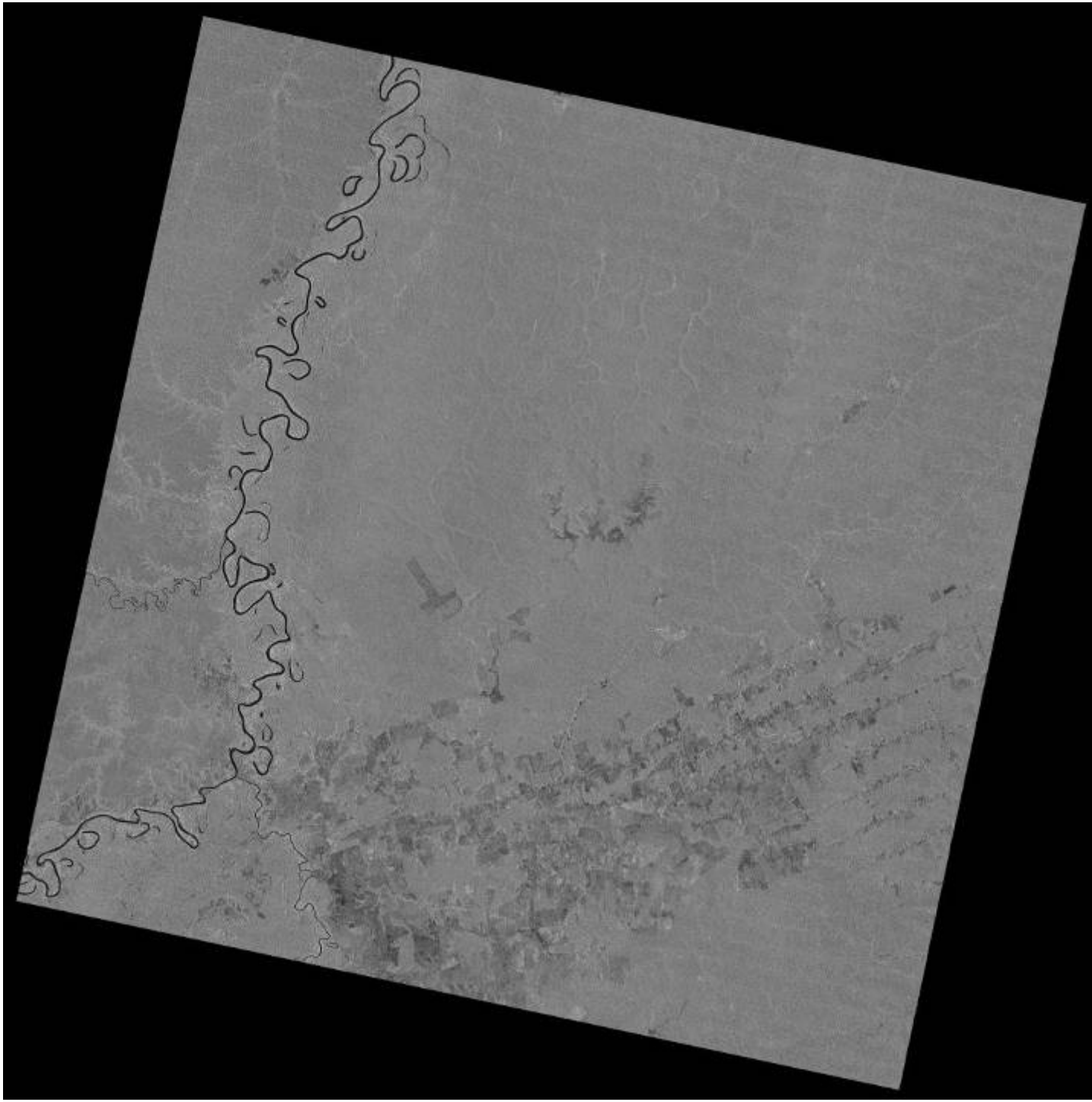


Radiometry

Multi-Mode Mosaic

β_0

i = 20°…45°



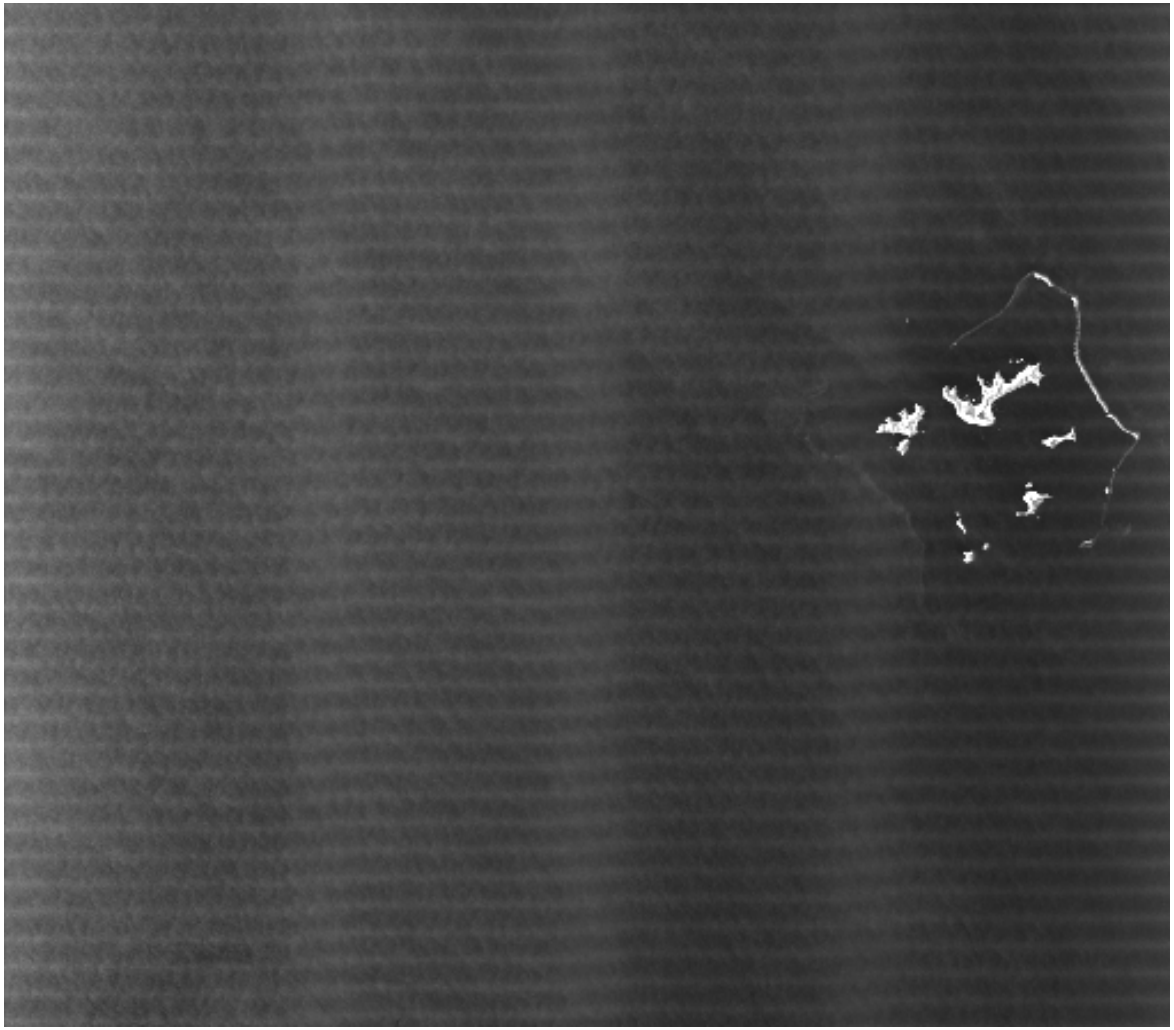
$$\gamma_0 = \beta_0 * \tan(i_{x,y})$$

ScanSAR
+ Stripmap
+ Spotlight
Mosaic

radiometrically corrected with *local* incidence angle *i*

Noise Correction

- The (receiver) **noise** level is measured for each data take by “Rx-only” calibration pulse sequences prior and after image acquisition
- From that, a **noise annotation** is derived taking into account the space-variant processor noise-gain (e.g. elevation beam correction and ScanSAR azimuth pattern correction).
- This **noise annotation** is part of the **L1b-product XML-annotation-file**.
- Due to the fact that the application of the space-variant noise annotation to the image data might be a burden to the user, all detected radiometrically enhanced products (MGD-RE, GEC-RE, EEC-RE) will be corrected for noise with the next processor release (December 1st).
- The corresponding flag in the **L1b-product XML-annotation-file** will be switched accordingly.



ScanSAR Image without Noise Correction

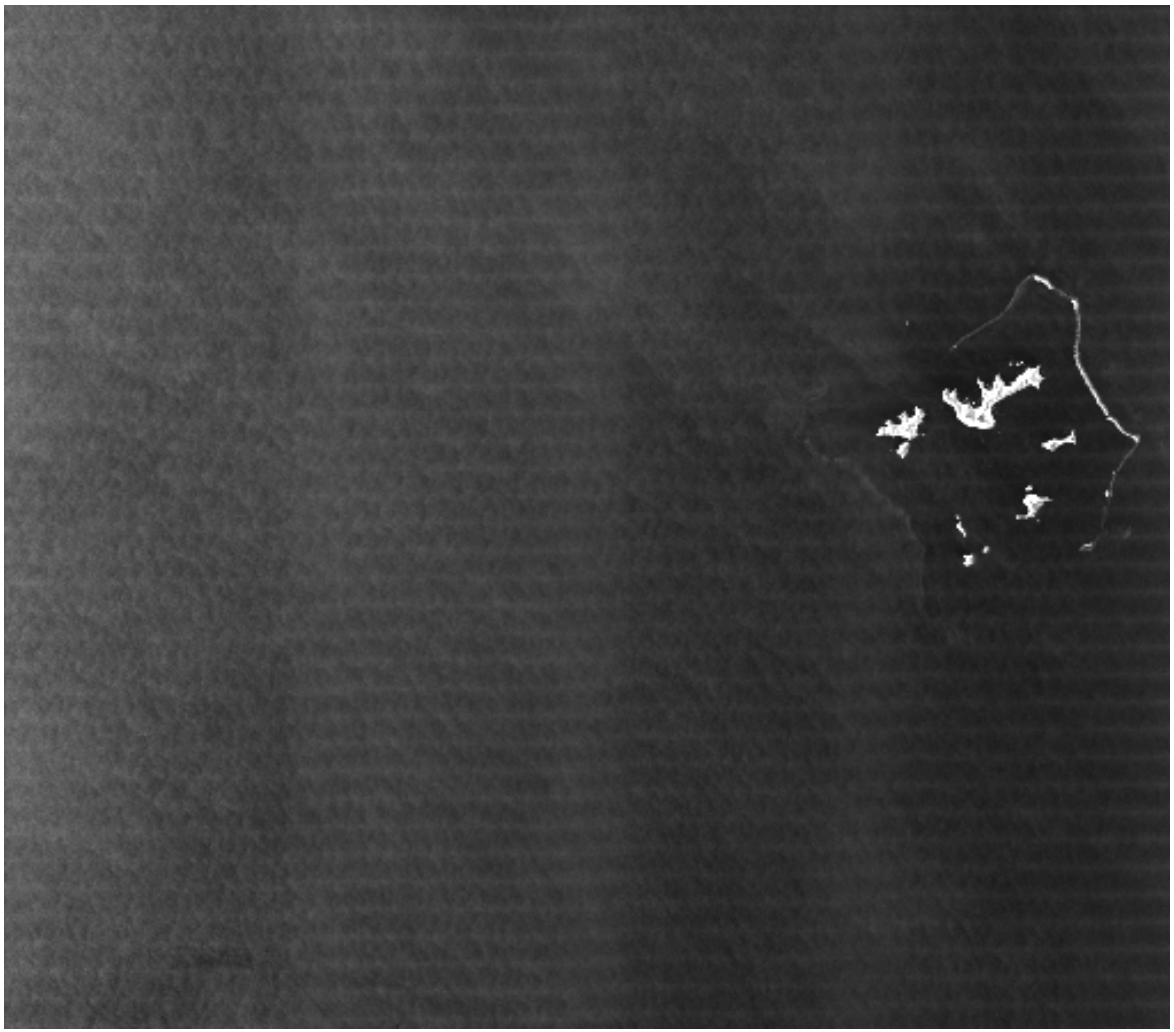
noise pattern
affects low
backscatter regions
in ScanSAR
datatakes

SNR at Sea Surface:

approx. 0 dB at
burst center

approx. -3 dB at
edges of burst (!)

U. Balss 2008



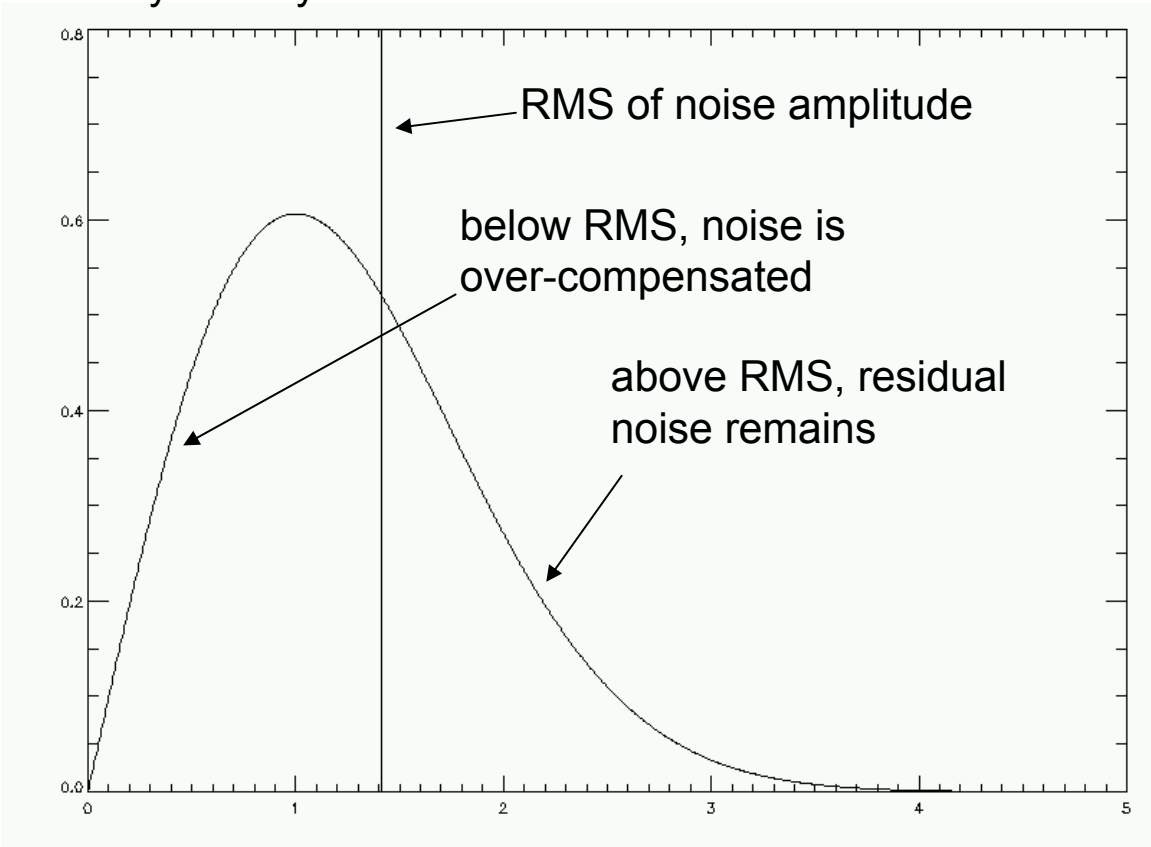
Noise Reduction by Subtraction of RMS of Noise Amplitude

There remains still some residual noise!

U. Balss 2008

Analysis of Residual Noise

probability density



noise amplitude

For high SNR:

In mean, the influence of both shown effects on signal power compensate each other.

For low SNR:

Over-compensation of noise is limited because signal amplitude cannot be lowered below zero.

Thus, both effects are no longer balanced and mean signal power is still affected by residual noise.

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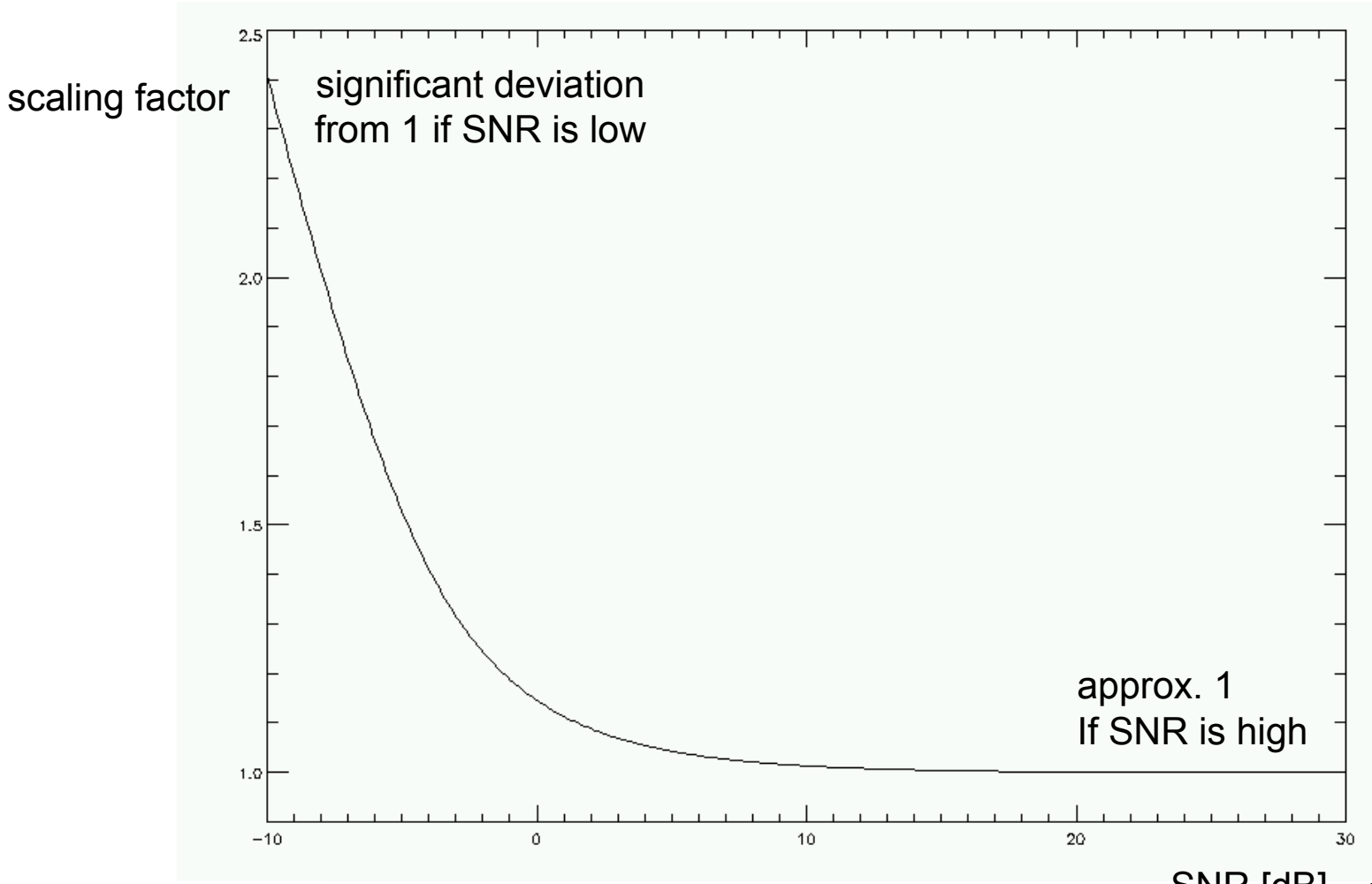
SNR Adaptive Scaling Factor



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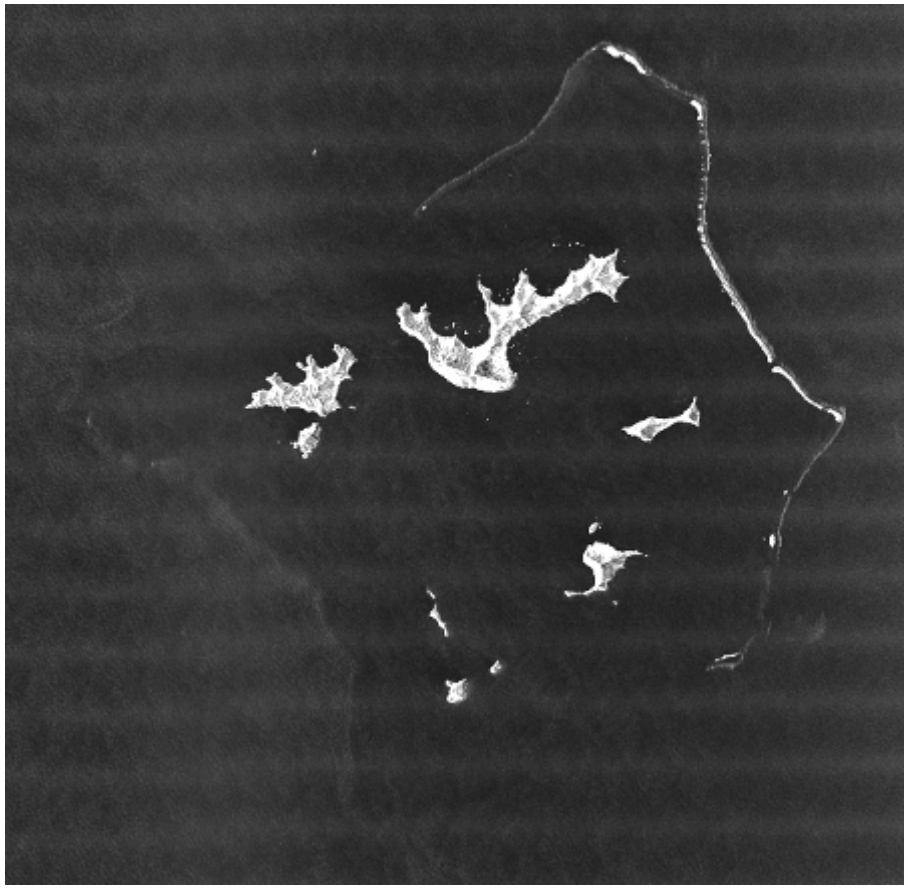
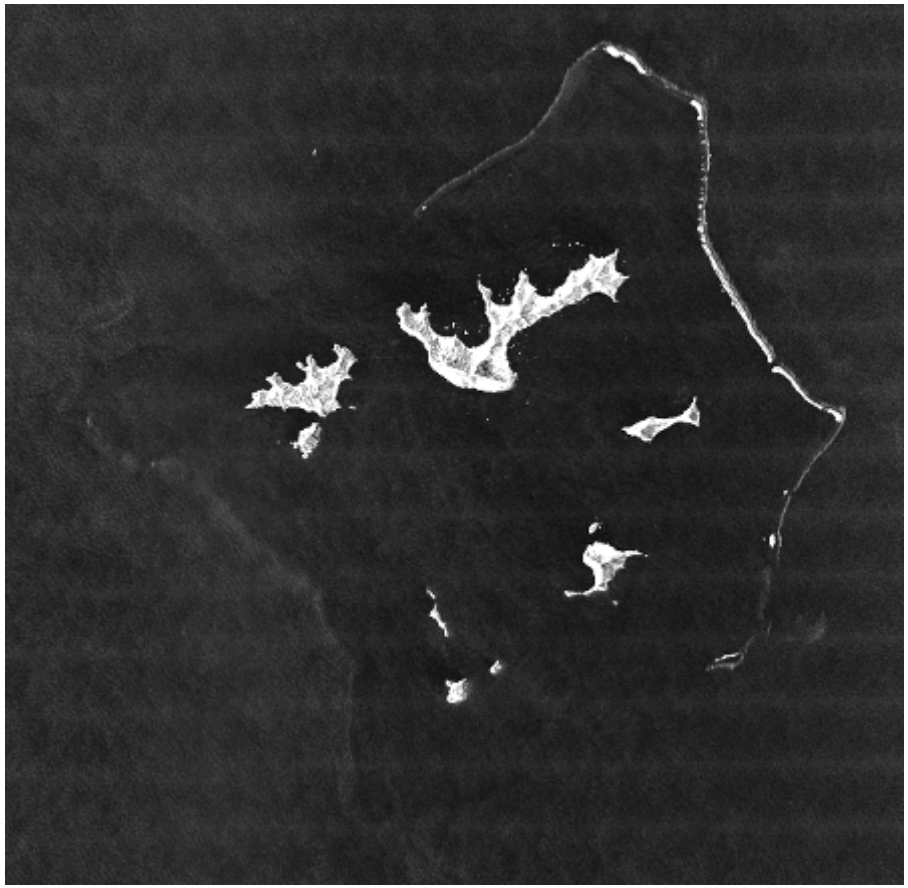
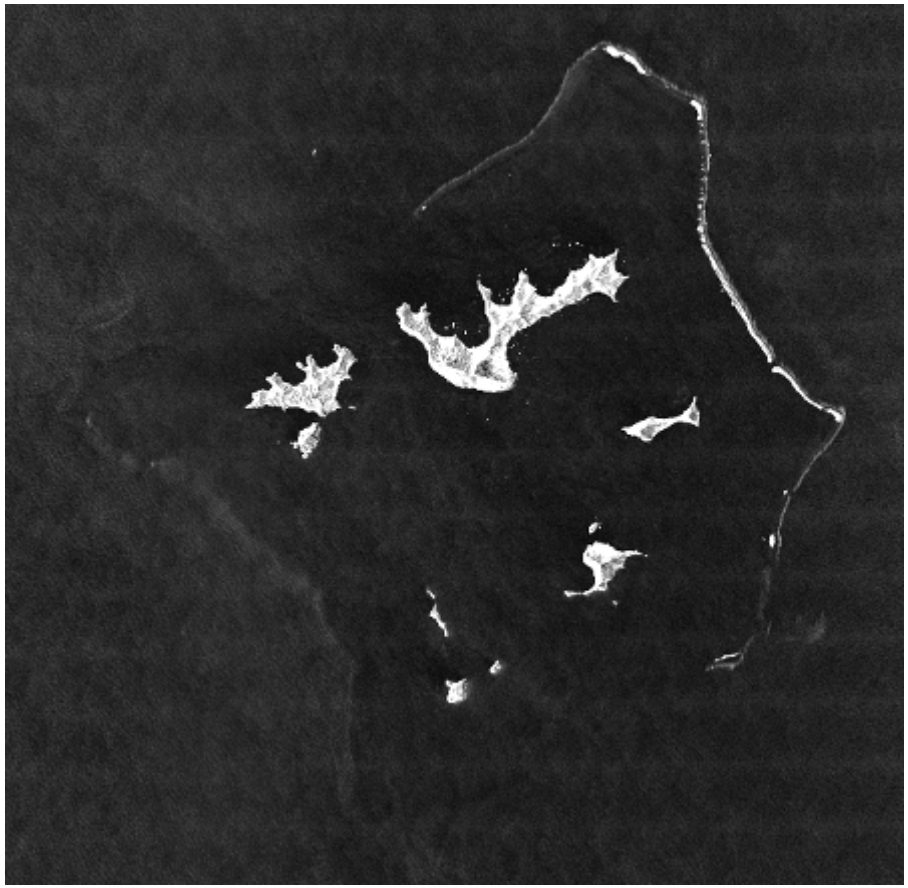
Without Noise Compensation



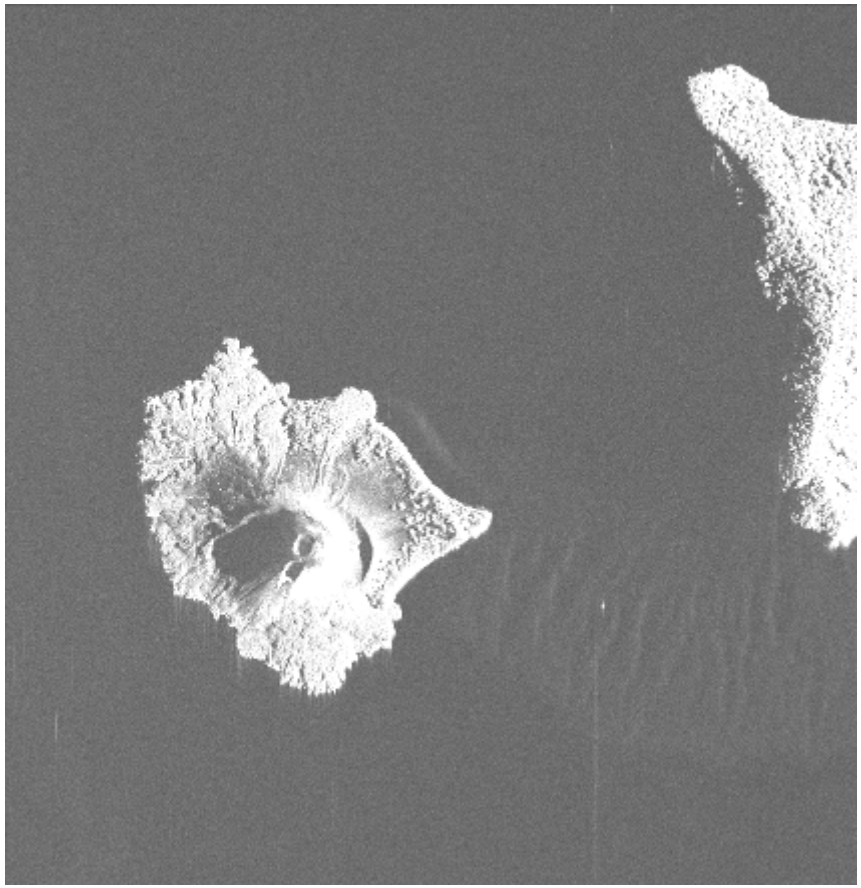
Usage of RMS of Noise Power as Clipping Level



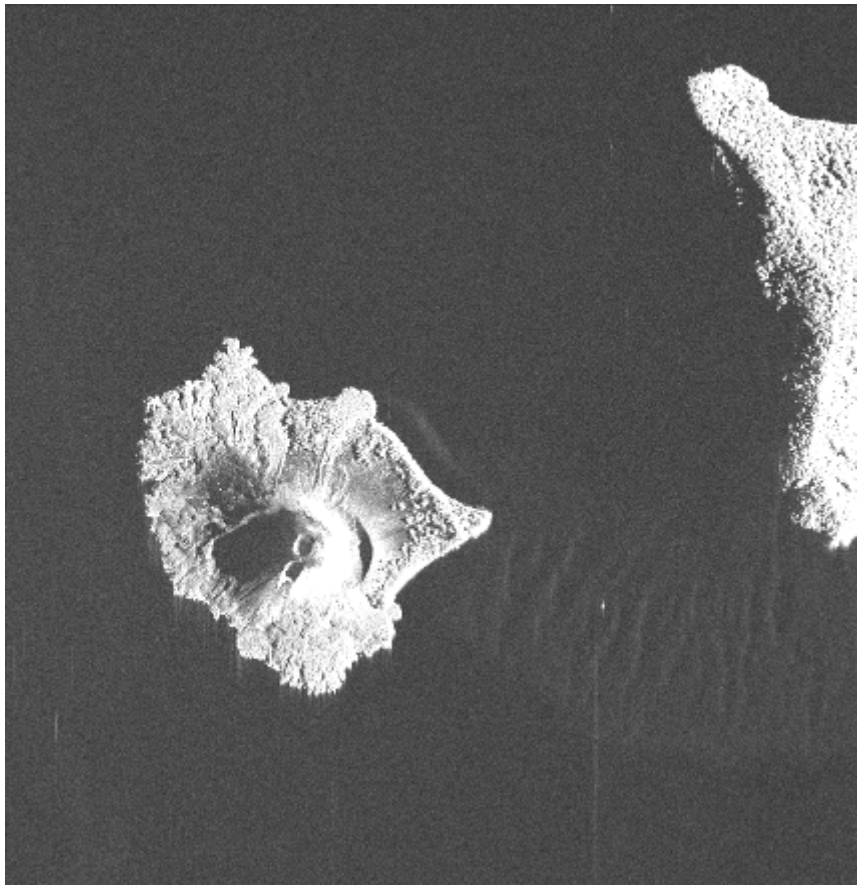
Usage of SNR Adaptive Clipping Level



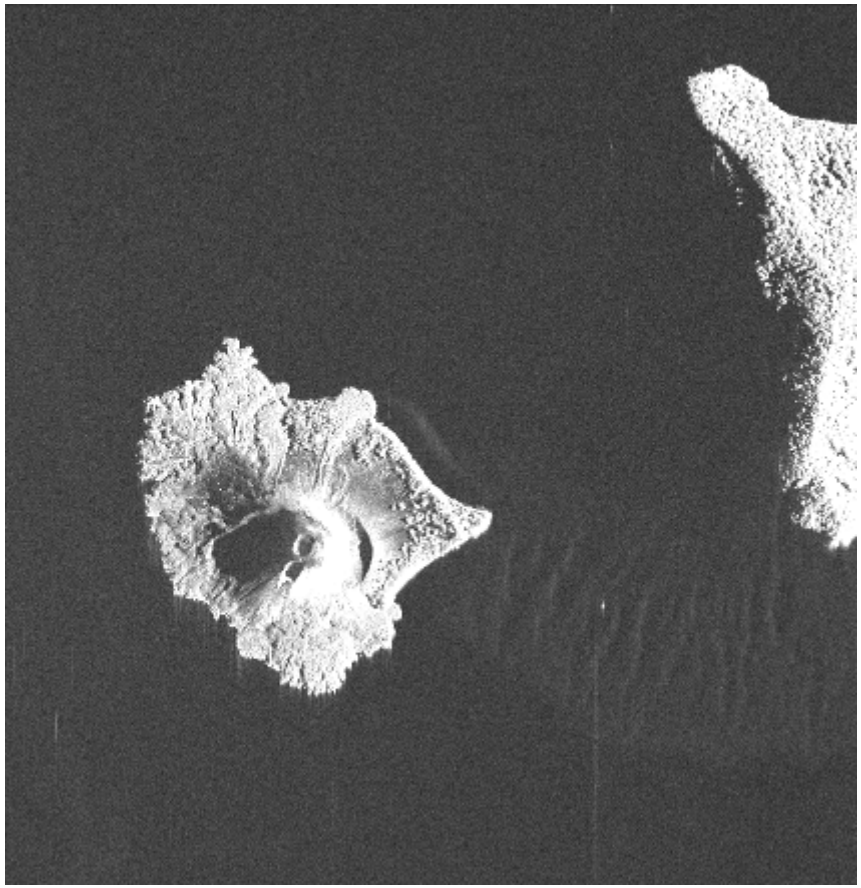
Without Noise Compensation



Usage of RMS of Noise Power as Clipping Level

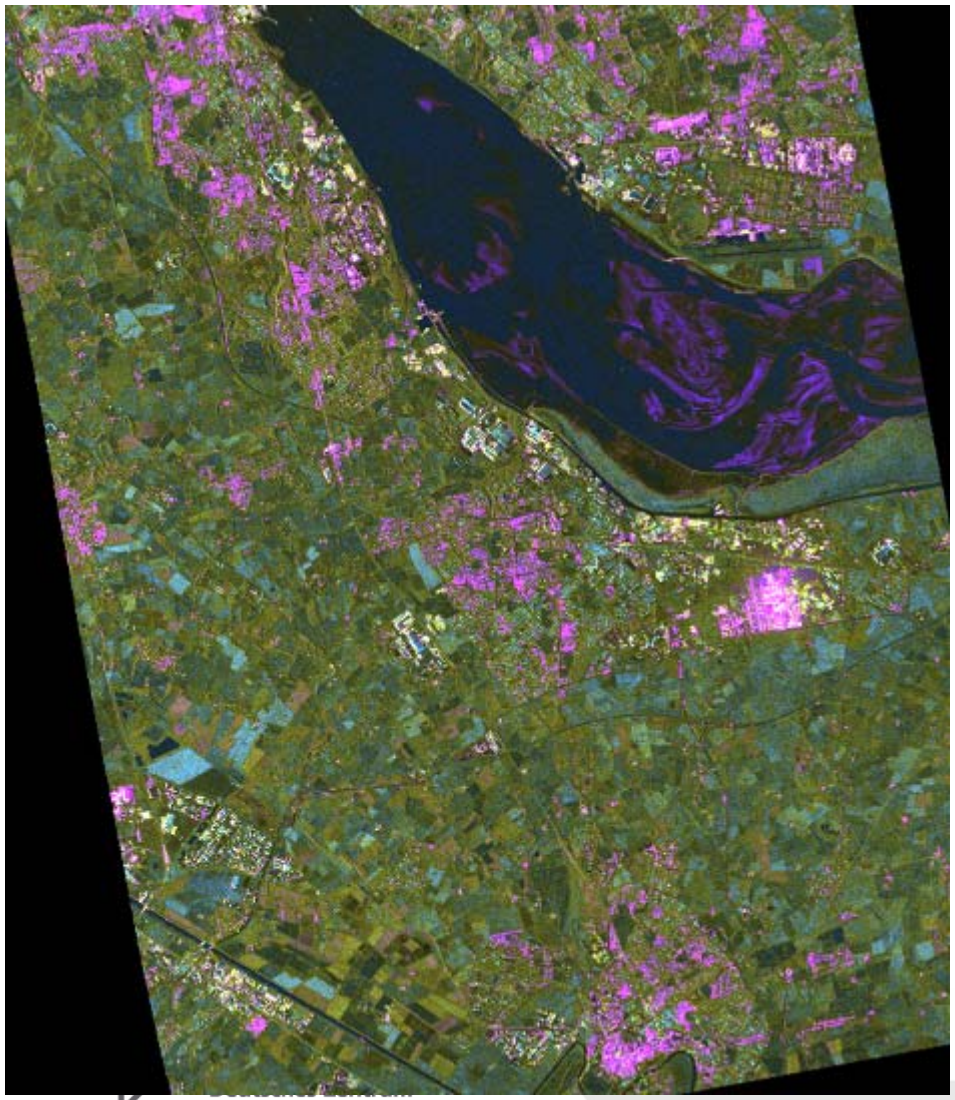


Usage of SNR Adaptive Clipping Level

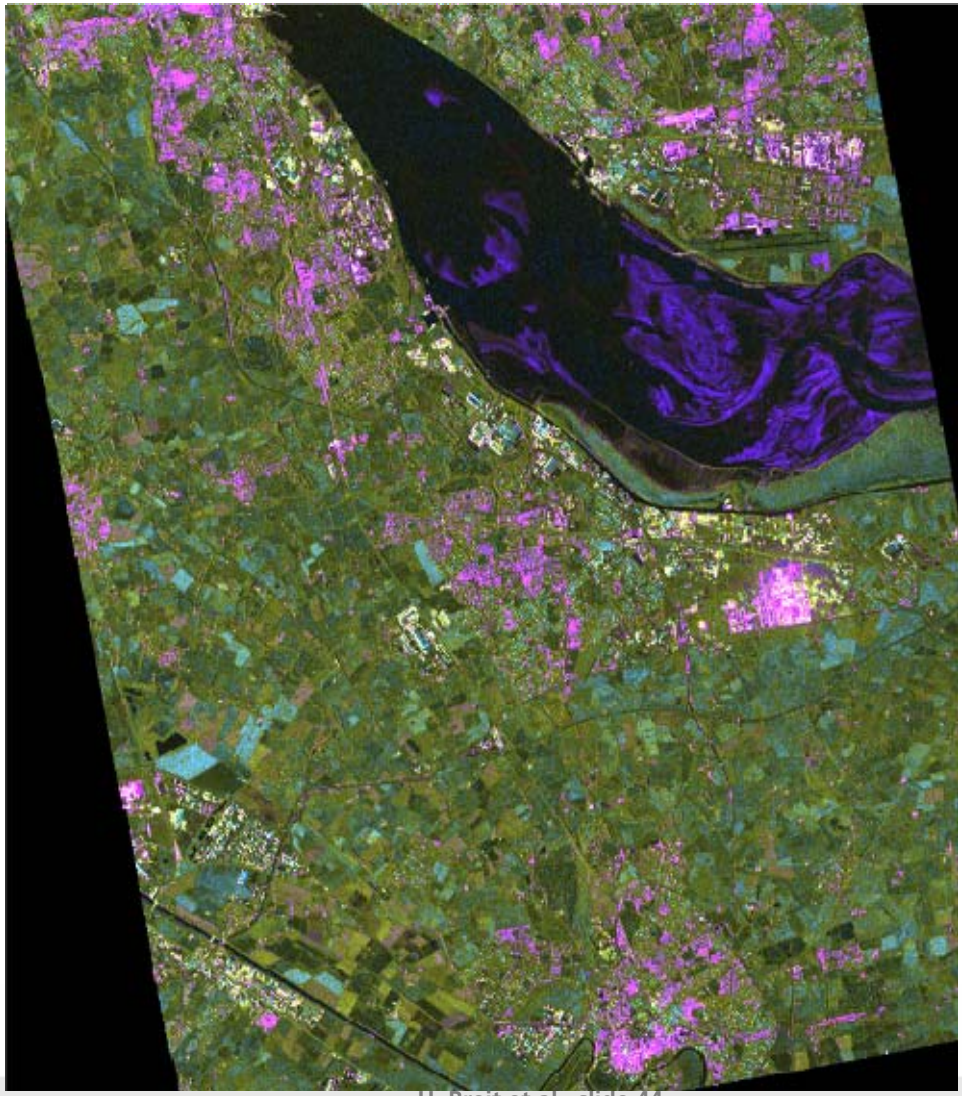


Noise Compensation For All “RE” Products: HH/HV SM Dual Pol Quicklook

without



with



Mosaic of **41 Spotlight EEC** RE Standard Products

Tool for automatic mosaicking and calibration by

T. Fritz / M. Lachaise (DLR IMF-SV)